

Growing Ornamental Greenhouse Crops in Gravel Culture

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CONTENTS

Acknowledgment	2
Introduction	3
Small Experimental Plots	4
Equipment	7
Benches	7
Tanks	8
Inlet Pipes	9
Automatic Siphon	9
Valves	11
Trough	11
Pumps	12
Time Clocks	12
Media	12
Solutions	14
Sources of Chemicals	15
Changing Solutions	15
Testing Solutions	16
pH	19
Aerating Solutions	20
Pumping	20
Planting	21
Pest Control	21
Specific Crops	22
Roses	22
Carnations	32
Chrysanthemums	32
Snapdragons	33
Gardenias	35
Lilies	37
Stocks	38
Sweet Peas	40
Asters	41
Boston Yellow Daisy	42
Pansy	43
Feverfew	44
Orchids	44
Miscellaneous Crops	45
Comparative Costs of Soil and Gravel Culture	46
Summary	48
Appendix	50
Bibliography	52

This revision of Ohio Agricultural Experiment Station Bulletin 616, published in 1940, is necessitated by the changes which have taken place in method and application.



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GROWING ORNAMENTAL GREENHOUSE CROPS IN GRAVEL CULTURE

D. C. KIPLINGER AND ALEX LAURIE

INTRODUCTION

"Gravel culture" is a general term which applies to the growing of plants without soil in an inert medium into which nutrient solutions are usually pumped automatically at regular intervals. Haydite (shale and clay fused at high temperatures), soft- or hard-coal cinders, limestone chips, calcareous gravel, silica gravel, trap rock, crushed granite, and other inert and slowly decomposing materials are included in the term "gravel."

As a laboratory technique, growing plants without soil in nutrient solutions dates back to the middle of the nineteenth century, to the original work of Bousingault, Liebig, Salm-Horstmar, and Sachs, who provided the mineral nutrition theory of today. Their techniques were elaborated and improved by such workers as Knop, Tollers, Pfeffer, Tottingham, Shive, Hoagland, and others.

The first practical application of growing plants without soil was made by Pember and Adams (12), who attempted to grow carnations in sand to determine their nutritional needs. Biekart and Connors (2) in 1927 succeeded in developing a satisfactory method of growing carnations in sand which was surface-flushed regularly with nutrient solutions. Laurie (8, 9) and his assistants were likewise engaged about the same time in growing different flowering crops in sand with additions of nutrients in dry form. Gericke (6) was one of the first to advocate the commercial use of water culture, the growing of plants with their roots constantly immersed in a nutrient solution.

Automatic subirrigation received its impetus from the work of Eaton (5), who demonstrated that solutions supplied automatically from below to sand saved much labor and were quite satisfactory. Withrow and Biebel (16) developed the original mechanics in 1936, and a little later a somewhat similar arrangement was introduced by Connors and Tiedjens (3). In 1937, workers at the Ohio Agricultural Experiment Station (10) began using the same method, following the mechanical setup of Withrow and Biebel. In place of sand, coarse aggregates were used.

The reasons for the attempts to apply such methods to the practical culture of crops in the greenhouse are several. Since soil is a complex medium, absolute control of nutrition is difficult, and even the most expert growers have crop failures frequently. The automatic subirrigation method with solutions supplied to plants growing in an inert medium provides an exact and uniform system of procedure with ease of modification to conform to environmental variations. The labor saved by such a procedure is likewise to be considered, as well as the continued use of the medium selected without the frequent changes necessary when soil is used. Further advantages lie in the greater uniformity of quality of the crops so produced and the possibility of higher production due to optimum growth conditions. It must be understood, however, that if perfection of growth is attained in soil, just as good quality and as high a production can be expected in soil as in soilless culture. Although it

is possible to grow many ornamental crops successfully, those which indicate greatest economic return on the investment are roses, gardenias, carnations, sweet peas, chrysanthemums, and snapdragons.

The work that was started in 1937 at the Ohio Agricultural Experiment Station has gradually progressed, and a considerable area of the greenhouse space is now devoted to soilless culture. A large variety of crops has been grown successfully, and many of the initial difficulties have been overcome, so that it is now safe to make specific recommendations with the expectation of success, provided these are followed exactly. Many commercial establishments have likewise tested this procedure, at first on a small scale, later gradually enlarging to devote considerable space to the growing of crops commercially without soil.

Because many small plots were needed to secure the required experimental data for this work, inexpensive units were devised by several graduate assistants (Arnold Wagner, Joseph Fueglein, Raymond Hasek, and D. C. Kiplinger) of the Ohio Agricultural Experiment Station and located at Columbus.

SMALL EXPERIMENTAL PLOTS

In figure 1 is diagramed the assembly of a unit containing a number of small plots. AP is an air pump controlled by time clock TC. B is a bleeder made by placing a pinch clamp over a piece of $\frac{1}{4}$ -inch by $\frac{5}{64}$ -inch rubber tubing and almost closing the aperture. A bleeder at each end of the main air line will be sufficient to allow for the escape of air following pumping so that the plots will drain quickly. The main air line consists of a pipe tapped and drilled at regular intervals to allow for the connection of $\frac{1}{4}$ -inch short nipples for air outlets. The area of the pipe for the main air line should be slightly greater than the sum of the areas of the air outlets. This size ensures uniform air pressure to each of the plots. O stands for air outlets for carboys made of $\frac{1}{4}$ -inch short nipples. The diagram illustrates how 40 plots can be operated simultaneously.

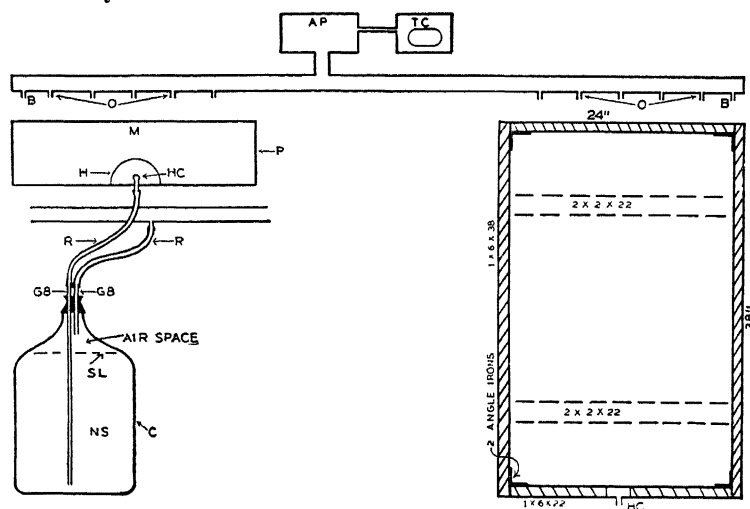


Fig. 1.—Diagram of a small plot assembly

P is the 2-foot by 3-foot by 6-inch experimental plot. H is the half-tile, M the medium to be used, and HC a male hose connection screwed into the front board. R is $\frac{1}{4}$ -inch by $\frac{5}{64}$ -inch laboratory rubber tubing cut long enough to allow for complete removal of the rubber stopper and glass tubing from the carboy for additions of water and nutrients.

G8 is 8-millimeter glass tubing. The short piece does not extend into the solution, but the long piece extends to one-half inch from the bottom of the 5-gallon carboy C. A No. 6 two-holed rubber stopper must fit tightly enough in the neck of the carboy to prevent the escape of air. SL is the level of the nutrient solution NS maintained in the 5-gallon carboy. The solution level SL should be maintained at the point illustrated in figure 1, as some air space is necessary to keep the nutrient solution from backing up into the main air line; furthermore, the volume of solution in the carboy at this point is just sufficient to fill the 2-foot by 3-foot by 6-inch plot within 1 inch of the top. Pumping to this level prevents algae growth on the surface of the medium.

An inexpensive pump and motor manufactured for paint spraying are adaptable for use as a source of compressed air. When the motor is in operation, compressed air is pumped through the main air line, and a uniform pressure is built up in the air space above the solution level SL in each of the carboys. This pressure forces the nutrient solution into the long piece of G8 glass tubing leading to the plot P and thereby fills the plot. A time clock is a convenient device for regulating the period necessary for the air pump to empty completely the carboy C. Some pumps are so constructed that air will leak back through them and thus dissipate the pressure. No bleeders are necessary with such pumps, as the solution will drain back by gravity into the carboy.

As many as 40 small plots can be operated successfully with a paint sprayer motor and pump. It will take about 10 minutes for pumping and 20 minutes for complete drainage of 40 plots operated simultaneously.

When the area of the main air line is slightly larger than the sum of the areas of the air outlets, pumping will be uniform so that plots in various sections of experimental greenhouses can be used, as is often necessary under various light, temperature, and other environmental conditions.

The construction of plots small enough to be filled from a 5-gallon carboy is diagramed to the right in figure 1.

The bottom of the plot is constructed by placing two pieces of 1-inch by 12-inch by 38-inch lumber side by side and nailing them to the two pieces of 2-inch by 2-inch by 22-inch lumber indicated by the dotted lines. These 2-inch by 2-inch by 22-inch pieces prevent sagging of the bottom when the plot is filled with medium. The sides are then cut to fit on top of the bottom of the plots. At this time a hole should be bored in the board that will be the front of the plot. The hole should be located flush with the bottom of the plot to allow for complete drainage of the plot after pumping. This hole is to accommodate the male hose coupling and should be slightly smaller than the diameter of the coupling to ensure a tight fit. The hose coupling should fit into a $\frac{1}{4}$ -inch or $\frac{3}{8}$ -inch hose to allow for ease of removal of the rubber tubing.

The sides are then nailed onto the plot bottom and to each other at the end. The 2-inch by 2-inch by 22-inch pieces should be underneath, not within the plot. Then the 2-inch angle braces should be screwed inside at each corner about 4 inches up from the bottom to prevent the boards from pulling apart when the plot is filled with medium. The plot is then waterproofed on the inside only with asphalt emulsion or any similar substance not toxic to plants.

Sometimes it is difficult to waterproof the plots completely because of warped boards. Strips of laboratory cheesecloth are laid on top of the wet asphalt emulsion at all points and are thoroughly impregnated by the application of additional emulsion. Two coats are usually sufficient. When the cheesecloth is placed behind the angle irons before they are permanently screwed in place, a greater margin of safety that the corners will remain waterproofed is secured.

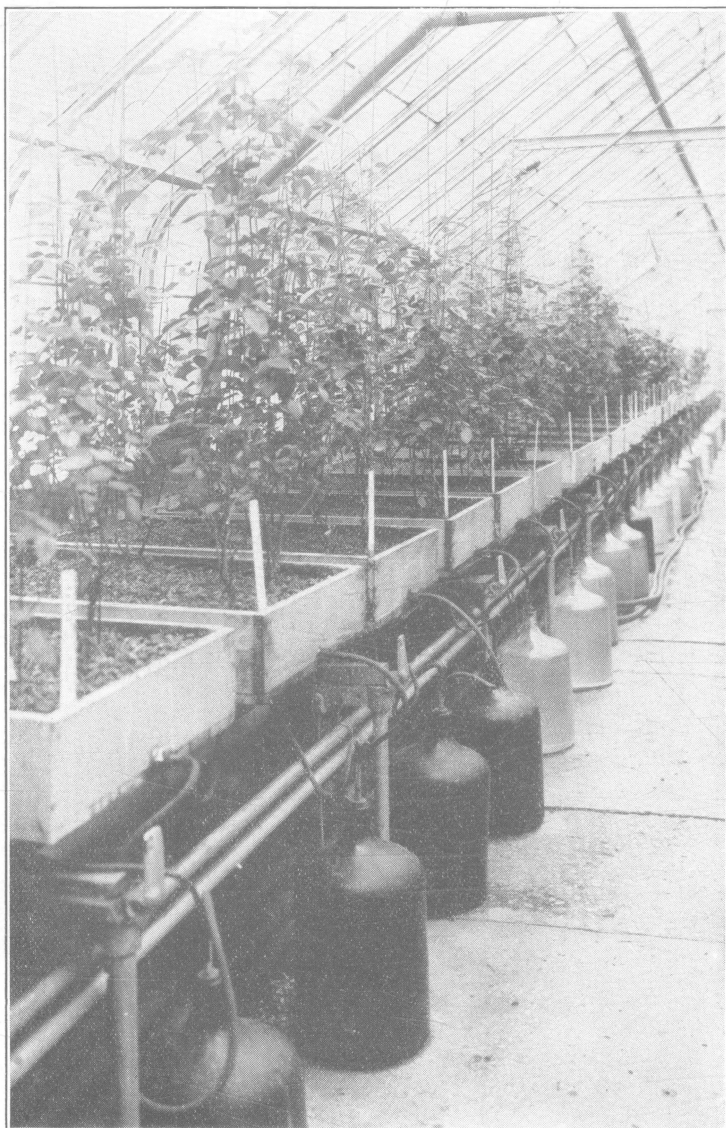


Fig. 2.—Numerous small plots can be operated successfully with an air compressor.

A container of similar dimensions constructed of reinforced concrete with provisions for drainage is more satisfactory than a wooden container. Leaks occur less frequently, and there is no danger that the sides will separate from each other or the bottom when the plot is filled with medium.

Before the assembled plots are filled with medium, the half-tile is placed on the bottom of the plot directly in line with the hose connection. An asphalted eaves trough may be substituted, but zinc toxicity is often encountered when the asphalt deteriorates. The purpose of the tile is to allow the solution to spread uniformly and quickly throughout all parts of the plot and to prevent the entrance of medium into the rubber tubing. The use of black iron window screen is advised at the joints and end of the tile. The tile should not fit perfectly on the bottom of the plot, because entrance and exit of the solution will be hindered. Pieces of wooden plant labels placed under the tile eliminate this difficulty.

After the equipment has been assembled, the plot is filled with medium and connected to the 5-gallon carboy. It is essential that the plots be tilted slightly toward the front to permit free drainage, as solution standing on the bottom of the plot seems to inhibit plant growth.

When all installations have been made correctly, the successful operation of many plots depends on the maintenance of the correct solution level in the carboys. The complete pumping of some plots while others are only partially pumped will result in a release of air pressure and immediate drainage of all plots.

EQUIPMENT

BENCHES

The most satisfactory bench for growing crops in inert media is made of concrete with a V bottom. A slope of $1\frac{1}{2}$ inches from the side to the center of the bench is sufficient, and no lengthwise slope to the bench is necessary if extra inlets and outlets are installed. Without the additional inlets and outlets, a lengthwise slope of 1 inch to 100 feet is desirable on benches not over 100 feet long. On longer benches, difficulties with uniform moistening of the medium will be experienced because of the slope. The sides of the bench may be 6 to 8 inches high.

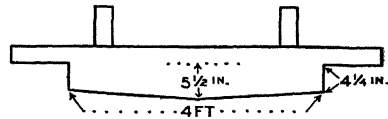


Fig. 3.—Form used to convert existing flat-bottomed wooden or concrete benches into a modified V bottom

If flat-bottomed concrete benches have already been built, they can be converted to gravel culture by the following method:

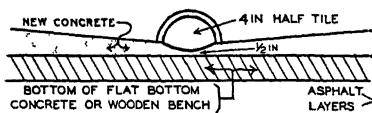


Fig. 4.—Detail of bottom of a modified V-bottom bench showing notch under the half-tile into which the solution finally drains

The inside of the bench should be covered with emulsified asphalt to prevent the old concrete from binding with the new, and if drainage holes are large, they should be covered with old cheesecloth and asphalt. A dry concrete mix should be prepared from a one to four mixture of cement and AAA Haydite or sand. This mixture is placed in the bench and tamped roughly into the form of the modified V. To finish the V in the bench, the form (fig. 3) should be

pushed down into the wet concrete and moved back and forth. The concrete should be smoothed with a metal trowel. To minimize the amount of water in the bottom of the V, a short length of 1-inch pipe should be rolled back and forth in the V to form a notch or small depression. The water that will stand then will be in the depression under the tile, and no damage will result. A layer of concrete at least one-half inch thick should be retained between the bottom of the V notch in the V and the top surface of the old bench, to prevent cracking of the new concrete (fig. 4).

Wooden benches with bottom boards running across the bench can be converted by placing additional supports under the bench to prevent sagging. The

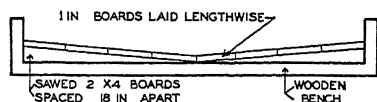


Fig. 5.—Construction detail of an all-wood bench

inside of the bench should be cleaned and the sideboards made level. The same procedure as outlined for the flat-bottomed concrete bench should be followed. Benches with bottom boards running lengthwise will sag unless heavy supports are placed between the bench legs. A wooden V can be made as shown in figure 5. For an all-wood bench, the joints must fit perfectly and the supports be rigid.

Both concrete and wooden benches should be coated inside with a watery dressing of asphalt emulsion and then covered again with a thicker coating. As soon as dry, the benches should be filled with water and tested for leaks. If any develop, a patch of cheesecloth covered with asphalt usually corrects the trouble. A cheap grade of emulsified asphalt, such as is used for road building, is satisfactory, provided it contains no oil or tar. One gallon of undiluted asphalt emulsion will cover about 50 square feet of surface.

TANKS

In order to provide suitable containers for the nutrient solutions, tanks are installed under benches or in other suitable locations. Such tanks have several requisites. They must be waterproof, acid resistant, and of sufficient size to hold about 40 per cent of the total volume of the benches that they fill. These tanks can be made of concrete, wood, or metal. For small installations, milk vats or even grave vaults have been used. All tanks made of concrete should be coated with sodium silicate diluted one part to four of water, emulsified asphalt, or both. Wooden and metal tanks should be coated with asphalt and made absolutely acidproof. It has been suggested that tanks should contain enough solution to equal the total volume of the benches instead of the 40 per cent recommended here. Although true that a larger volume of solution makes it easier to maintain the proper levels of nutrients, the additional costs of construction are so high as to make such recommendations impractical. For benches over 100 feet long, tanks can be placed in the middle of the house.

Although individual tanks for benches are recommended on small installations, in commercial practice with a single crop or variety, as many as 12 benches have been supplied from one tank. This arrangement is not advisable if several crops are being grown simultaneously, for then the advantage of solution manipulation is nullified.

INLET PIPES

Black iron pipe, not galvanized, should be used for the inlets. For a 100-foot bench, one inlet of 1- or 1½-inch pipe near the pump at the end of the bench is sufficient, although better drainage can be provided by the placing of a separate pipe under the bench or alongside (fig. 6 and 7). The size will depend on the length of the bench. For small installations, 1½-inch pipe will suffice. Proportionally larger sizes are needed for long benches. Openings of 1-inch pipe spaced 20 feet apart in the bottom of the V in the bench are connected to the pipe line under the bench by rubber hose or other suitable material. Where several benches are so equipped, the pipe lines should connect to a central header whose area is slightly greater than the sum of the areas of the pipe lines leading from it.

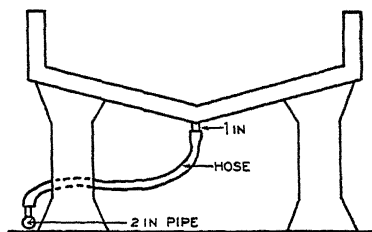


Fig. 6.—Pipe for extra inlets placed alongside the bench instead of underneath

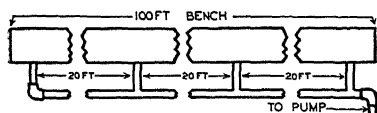


Fig. 7.—Lengthwise view of 100-foot bench with placement of extra inlets

Uniform pumping of all benches will be obtained, for the pressure of the solution at all pipe openings in the header will be equal. All inlets to the bench should be flush with the bottom of the V and completely waterproofed, since they are frequently the sources of leaks.

AUTOMATIC SIPHON

Drainage of the nutrient solution back through the pump is often slow because of the presence of the pump impeller. An automatic siphon (fig. 8) facilitates rapid drainage from the bench, as most of the solution does not pass through the pump.

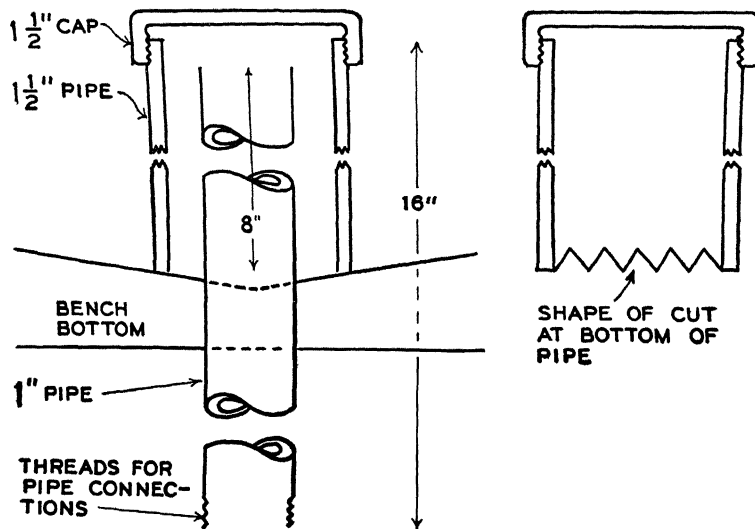


Fig. 8.—Automatic siphon for rapid drainage of benches

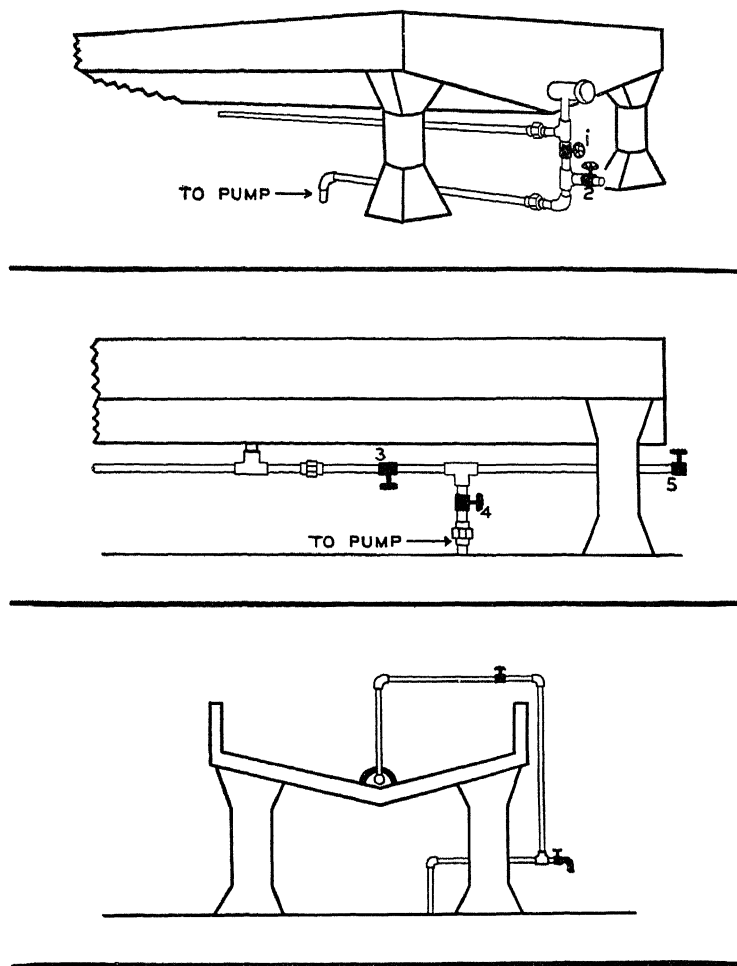


Fig. 9.—Upper section—Bench construction and valve arrangement with inlet located at end of the bench

Middle section—Bench construction and valve arrangement with inlet located under the bench

Lower section—Cross section of V-bottom bench showing half-tile and pipe arrangement for flooding bench prior to spraying

The height of the inner pipe should be no more than the desired solution level in the bench. The diameter of this pipe should be no smaller than 1 inch, with the outside pipe 1½ inches in diameter. The bottom of the outside pipe resting on the bench bottom should be notched or cut in a sawtooth fashion to facilitate entrance of the solution. The solution rises in between the two pipes as the bench is being flooded, and the solution begins to overflow into the central pipe when the bench is pumped to the desired level. The suction of the solution removes all the air underneath the cap, and the siphon action continues until air is sucked in at the bottom of the outside pipe. Complete drainage of the small amount of solution remaining in the bench is through the pump. The longer the pipe extends underneath the bench, the more rapid is the flow of the solution through the siphon.

VALVES

Figure 9 indicates the method of manipulating valves when spraying is done and solutions are changed. In the upper diagram of figure 9, for normal operation, valve 1 should be open and valve 2 should be closed. To pump out the tank, valve 1 should be closed and valve 2 opened. To flood the bench prior to spraying, valve 1 should be closed. To drain water from the bench after spraying, the cap on the pipe projecting from the end of the bench should be removed. In the central diagram of figure 9, for normal operation, valves 3 and 4 should be opened and valve 5 closed. To pump out the tank, valve 3 should be closed and valves 4 and 5 opened. To flood the bench prior to spraying, valve 3 should be open and valves 4 and 5 closed. To drain water from the bench after spraying, valve 5 should be open.

TROUGH

To obtain rapid spread of the solution in the bench, any one of the following suggested methods is satisfactory: half-tile (fig. 10), eaves troughs with beads removed, or a wooden inverted V. The eaves trough should be asphalted

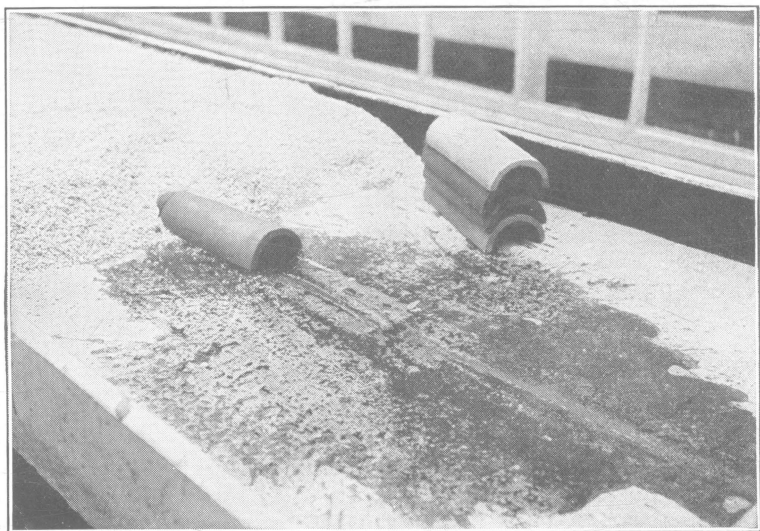


Fig. 10.—Half-tile used as a solution channel. Note the inlet from below the bench in the center of the picture and the notch at the bottom of the concrete in this modified V-bottom bench.

to prevent zinc damage, and wedges should be placed between it and the bench bottom to allow for entrance and exit of the solution. Large cracks or openings should be covered with black iron screen to prevent the medium from clogging the trough.

PUMPS

Either a sump or side-suction centrifugal pump can be used for flooding the bench. Sump pumps are easier to install, since a separate compartment is unnecessary in the tank to keep the motor dry.

The quicker the pumping and drainage are completed, the better the results. Benches should be filled in at least 30 minutes and should drain in 60 minutes. The following pumps have been used in tests and found satisfactory:

Deming No. 4000-M—No. 1 Side Suction Centrifugal Pump. When ordering, specify that a grease cup be supplied rather than the water-lubricated mechanism at the main bearing. Capacity 30 gallons per minute, 10-foot head. Deming Company, Salem, Ohio.

Deming No. 4602—Sump Pump. Capacity 40 gallons per minute, 10-foot head.

Gould "Cid" Sump Pump—No. 3151. Gould's Pumps, Inc., Seneca Falls, New York.

Myers No. 6101 Sump Pump. Capacity 25 gallons per minute, 10-foot head. F. E. Myers & Bro. Co., Ashland, Ohio.

Other manufacturers make pumps that are just as suitable. Allow at least 6 inches from the surface of the solution to the electrical box on all sump pumps for slopping of the solution when agitated.

TIME CLOCKS

Electric clocks (fig. 11) ensure regular pumpings. The present empirical recommendations of so many times per day serve the purpose. The following types are available:

Type T-27 Time Switch, Single Pole, Single Throw, General Electric Co., Schenectady, New York. Specify whether 115 V or 230 V clock is desired. Any number of additional "on" and "off" tabs can be secured.

Type K-11 Sangamo Time Switch, Sangamo Electric Co., Springfield, Illinois, is satisfactory if a maximum of three pumpings per day is desired.

MEDIA

The most satisfactory material for the growth of plants with the sub-irrigation method is one that is inert, does not give off any undesirable elements, does not change the pH, retains a sufficiency of water, and does not disintegrate. To date, there is nothing that approximates this ideal so closely

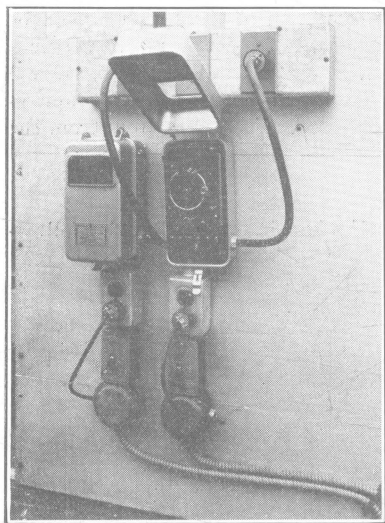


Fig. 11.—Time clocks used for automatic control of the number of pumpings per day

as Haydite, which can be obtained from the Hydraulic Press-Brick Co., South Park, Ohio. Where trap rock, granite chips, and silica gravel (acid) are available, they serve the purpose as well as Haydite. The B grade of Haydite, composed of a mixture of coarse (three-eighths inch in diameter) and fine particles is the most suitable size, although it has been found that finer sizes may be more suitable, particularly when inadequate drainage is provided. Because of the coarseness of the medium, there is a tendency for the roots to form at the bottom of the bench instead of throughout the entire body of the medium. This condition is probably due to excess aeration. The formation of the entire root system at the bottom necessitates complete drainage, else damage may occur to the roots even though a very small amount of solution remains standing (fig. 12 and 13). In finer media, root development occurs over a greater territory, and standing solution at the bottom may not cause serious damage.

Hard- and soft-coal cinders may likewise be used, although statements about their cheapness should be tempered, since screening and leaching consume time and labor. Cinders vary with the source of coal and in some localities may contain toxic substances. Excess of boron has been found in some localities and if present can be neutralized by the addition of 10 cubic centimeters of commercial sodium silicate to 100 gallons of solution. This addition may be made even after the plants are benched. Some cinders disintegrate readily and may be troublesome because of high water-holding capacity and insufficient aeration. Occasionally cinders are alkaline and may precipitate iron, phosphorus, and manganese. As a precautionary measure, cinders should be leached thoroughly. One-fourth to one-half inch is a suitable size for cinder particles.

Calcareous gravels are suitable for crops that grow satisfactorily in a pH of 7 or above. As a consequence of the high pH, precipitation frequently occurs. When these gravels are used, a precaution recommended is the broadcasting of monocalcium phosphate at the rate of 5 pounds to 100 square feet before planting. This material should be watered in thoroughly. Apparently after a period of time, a coating of phosphorus over the gravel particles minimizes the initial difficulties with high pH. Calcareous gravels are particularly unsuitable for roses and gardenias. Particles one-fourth to one-half inch in size are best.

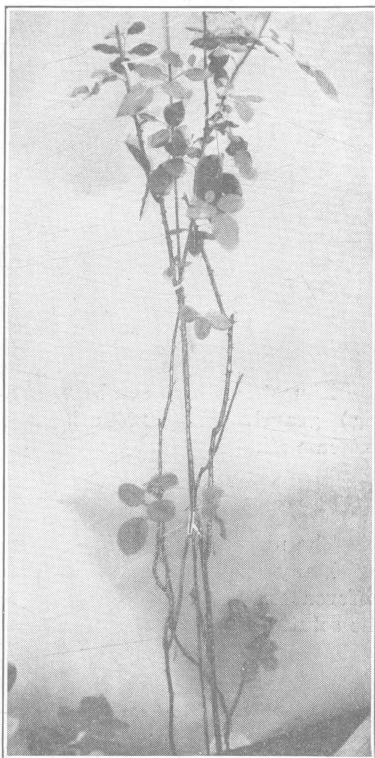


Fig. 12.—A Joanna Hill rose grown in a flat-bottomed bench where water was standing. Note extreme defoliation and chlorosis of leaves near the top of the photograph.



Fig. 13.—Standing water in a flat-bottomed bench—
an undesirable environment for optimum
plant growth

Limestone chips can be used in a manner similar to calcareous (lime-bearing) gravel. Slag from blast furnaces should be avoided because of its extreme alkalinity and possible toxic content.

SOLUTIONS

The nutrient elements are supplied to plants in solution form.

Many different formulas have been advocated by various workers. The differences between them are not very great, but to save confusion, we present the solution which has proved satisfactory on many crops.

Composition of the WP* formula

Chemicals	Per 1,000 gal. of water
Potassium nitrate	5 lb. 13 oz.
Ammonium sulfate	15.5 oz.
Magnesium sulfate	4 lb. 8 oz.
Monocalcium phosphate	2 lb. 6.5 oz.
Calcium sulfate	10 lb. 12 oz.
Total	24 lb. 7 oz.

*Developed by Arnold Wagner and G. H. Poesch of the Horticulture Department of the Ohio Agricultural Experiment Station.

The chemicals given in the formula can be mixed together in dry form. The mixture will not deteriorate and can be stored and used as needed.

Because of the present difficulty of securing the commercial grade of potassium nitrate, the following modification of the WP formula is suggested:

Chemicals	Per 1,000 gal. of water
Calcium nitrate	7 lb.
or	
Sodium nitrate	5 lb.
Potassium chloride	5 lb.
Ammonium sulfate	1 lb.
Magnesium sulfate	4 lb. 8 oz.
Monocalcium phosphate	2 lb. 8 oz.
Calcium sulfate	5 lb.

The chemicals in this latter formula should be weighed out individually and mixed in the tank.

The various grades of superphosphate may be used in place of monocalcium phosphate. Proportionally more must be added because of the lower percentage of phosphorus and the decrease in solubility.

A one-half strength WP solution should be used for the first 2 to 3 weeks on all newly planted crops. When the plants have become well established, a single-strength solution is applied. In 5 to 6 weeks from the time of planting, the concentration can be raised to a 2 WP level by adding twice the amount of chemicals per 1,000 gallons of water recommended in the WP formula.

The use of a nutrient solution in which ammonium sulfate alone serves as a source of nitrogen has not proved satisfactory with many crops, as they did not tolerate the high concentration of ammonia. Frequent additions of very small amounts of ammonium sulfate as a source of nitrogen show some promise. Uramon, a trade-name product for urea, may be used satisfactorily.

Manganous sulfate should be added to all solutions each month. One ounce of manganous sulfate is dissolved in 1 gallon of water acidified with three to five drops of commercial sulfuric acid. All this solution should be used for 1,000 gallons of nutrient solution. Iron should be added weekly in the form of ferrous sulfate at the rate of 4 ounces per 1,000 gallons.

SOURCES OF CHEMICALS

The chemicals used are of commercial grade and are reasonably priced.

Commercial potassium nitrate is difficult to obtain and for the present should be eliminated from consideration. Calcium nitrate can be obtained from the Synthetic Nitrogen Products Corporation, New York, New York.

Monocalcium phosphate can be obtained from the Monsanto Chemical Company, St. Louis, Missouri, Akron, Cleveland, or Cincinnati, Ohio. The reason for the use of this food-grade material is its low fluorine content. The fluorine may not be as dangerous as originally thought, however, and treble phosphate has been used satisfactorily.

Sodium nitrate, potassium chloride, ammonium sulfate, calcium sulfate, magnesium sulfate, superphosphate, and ferrous sulfate can be obtained from local dealers. Since only small amounts of manganous sulfate are necessary, they can be obtained from a druggist.

Since the materials used are not chemically pure, they contain the necessary trace elements without additions except those mentioned. Recommendations for adding boron, zinc, copper, and other elements should not be followed without specific advice. Considerable damage has resulted in some cases because of overzealousness. The addition of small amounts of thiourea, tryptophane, liquid manure, indolebutyric acid, sugar, nicotinic acid, or vitamin B₁ has not proved beneficial.

CHANGING SOLUTIONS

The original recommendation called for a change of solutions weekly, but at present no complete change is necessary more frequently than once in 2 months. In some instances, solutions have not been changed for several months, but as a precautionary measure, a change every 2 months is advocated.

TESTING SOLUTIONS

The Simplex Soil Testing Kit or the LaMotte Soil Testing Kit can be used for general purposes. The Simplex is sold by the Edwards Laboratory, Lansing, Michigan, the LaMotte by the LaMotte Chemical Co., Baltimore, Maryland.

The nutrient levels usually maintained in gravel culture are considerably higher than those in soil, and color charts in the test kit instruction booklets are of no value unless the nutrient solutions are diluted before being tested. A quick and accurate method of diluting and testing solutions, together with several precautions, is as follows:

Since small volumes of solutions are used, accuracy is essential, and either 1- or 5-cubic centimeter graduated pipettes are desirable. Medicine droppers used in the tests vary in size, but uniform drops can be obtained by holding the dropper at a 30-degree angle from the horizontal when measuring reagents or solutions. This position reduces the possibility of air bubbles' interfering with the drops at the lower end of the dropper. Usually the medicine droppers will deliver 20 drops per 1 cubic centimeter. Knowing the number of drops per cubic centimeter is helpful when high dilutions are made, as it is often convenient to begin with one-half cubic centimeter rather than one.

To insure against contamination, rinsing the equipment with tap water, then distilled water is essential. The placing of a carboy of distilled water on a shelf above the sink where the solutions are tested is desirable. A siphon can be made of a few pieces of glass and rubber tubing and will bring the water within convenient handling distance under sufficient pressure for quick rinsing. A pinch clamp on a short piece of rubber tubing at the lower end of the distilled water line is a convenient shutoff valve.

The nitrate nitrogen levels in nutrient solutions usually vary between 200 and 1,000 parts per million, but the recommended test kit booklets contain color charts only up to 25 parts per million. The nutrient solution must be diluted sufficiently to fall within the range of the color charts. This dilution can be accomplished by placing 1 cubic centimeter of a nutrient solution in one of the small glass vials in the test kits and adding 3 cubic centimeters of distilled water with either a pipette or calibrated medicine dropper. This solution should be mixed thoroughly by shaking. With reference to figure 14, which is a diagram of a nitrate spot plate, one drop of the diluted nutrient solution should be transferred with a clean medicine dropper to wells No. 1, 2, 3, 7, 8, and 9. With a clean dropper, distilled water should be added in the following order: one drop to well No. 2, two drops to well No. 3, three drops to well No. 7, four drops to well No. 8, and five drops to well No. 9. The solution in well No. 9 should be mixed thoroughly by running it up and down several times in the dropper by giving the rubber cap a pinch and releasing slowly several times. One drop of the solution in well No. 9 should be transferred to well No. 12. In the same manner of mixing and then transferring, one drop of solution in well No. 8 is taken to well No. 11, one drop of solution in well No. 7 to well No. 10, one drop of solution in well No. 3 to well No. 6, and one drop of solution in well No. 2 to well No. 5. It is not necessary to clean the dropper between each transfer, but it is essential to remove any droplets of solution remaining in the dropper by a quick shake before proceeding to the next well.

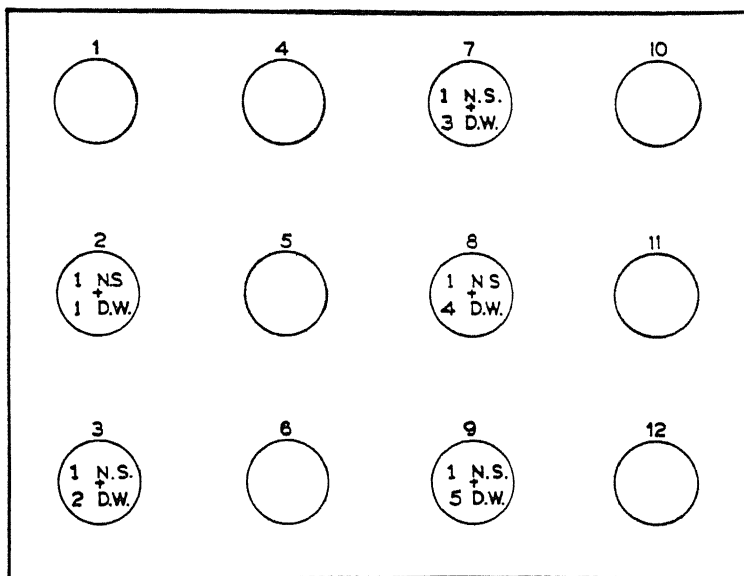


Fig. 14.—A nitrate spot plate

Abbreviations n. s. and d. w. are nutrient solution and distilled water, respectively, and numerals within the circles indicate the number of drops.

The nitrate reagent from the test kit should be added in the correct amount to wells No. 1, 5, 6, 10, 11, and 12. With reference to the Simplex kit, the readings in these wells would be, respectively, 100 parts per million, 200 parts per million, 300 parts per million, 400 parts per million, 500 parts per million, and 600 parts per million. For accuracy, a comparison of the color obtained in the nitrate spot plate should be made only with the highest reading on the color chart, which is 25 parts per million with the Simplex kit. Should the nutrient solution contain more than 600 parts per million of nitrate nitrogen as shown by the presence of a dark blue or bluish-black color in well No. 12, it will be necessary to add more than 3 cubic centimeters of distilled water to the 1 cubic centimeter of nutrient solution. The scale of dilution and the factor for multiplication of the readings in the wells are as follows:

Cc. of nutrient solution	Cc. of distilled water added	Factor for multiplication of readings in the wells
1	0	1
1	1	2
1	2	3
1*	3*	4*
1	4	5
1	5	6

*Used in the example.

It is essential to use only the reading of 25 parts per million on the nitrate color chart when making comparisons, in order to obtain accurate readings.

The methods of testing for phosphorus and potash are similar to each other except that different reagents are used for each of the tests. The maximum amount of phosphorus that can be read with the color chart of the Simplex system is 5 parts per million, and the maximum of potash is 20 parts per million. Dilution of the nutrient solution is necessary in order to bring the reading within the range of the color chart. This dilution is accomplished by transferring 1 cubic centimeter of nutrient solution to one of the small glass vials in the test kits and adding various amounts of distilled water to the vial. The contents should be shaken to ensure mixing, and all but 1 cubic centimeter discarded before the test is made, as the directions for each of the tests require that only 1 cubic centimeter be used. The scale of dilution and the factor for multiplication of the readings in the vial are as follows:

Cc. of nutrient solution	Cc. of distilled water added	Factor for multiplication
$\frac{1}{2}$	0	*
$\frac{1}{2}$	$\frac{1}{2}$	2
$\frac{1}{2}$	1	3
$\frac{1}{2}$	$1\frac{1}{2}$	4
$\frac{1}{2}$	2	5
$\frac{1}{2}$	$2\frac{1}{2}$	6
$\frac{1}{2}$	3	7
$\frac{1}{2}$	$3\frac{1}{2}$	8
$\frac{1}{2}$	4	9
1	0	1
1	1	2
1	2	3

*It is not possible to use this particular dilution, because the test requires the presence of at least 1 cubic centimeter of solution before it can be made. This was inserted as a guide for a possible error.

The tests for calcium and ammonia usually fall within the limits of the color charts, and no dilutions are necessary. The iron test is not entirely satisfactory and cannot be used as a guide for iron additions. Other tests for nutrients given in the test kit booklets need not be made unless unexplained difficulties arise which are not due to an unbalance of the nutrients for which the tests have been described.

TABLE 1.—Analysis of nutrient solutions in parts per million

	WP		2WP	
	Calculated	Fresh solution	Calculated	Fresh solution
Nitrates	400	400	800	750
Ammonium	28	25	56	50
Phosphorus	65	60	130	120
Potassium	250	250	500	500
Calcium	310	150	620	250

The analysis of a WP and 2 WP solution is given in table 1. The differences between the nutrient levels of the calculated and fresh solutions are accounted for by precipitation of the nutrients, low solubilities, or inaccuracies of the present quick tests.

Since phosphorus may readily precipitate from the solution or be absorbed by the plant, tests and additions should be made weekly. Nitrate and potassium tests made every other week after changing are sufficient. It is not

necessary to test for magnesium unless solutions are infrequently changed. Addition of the full amount of magnesium sulfate every 2 months is advocated. The nutrient levels given in table 2 can be maintained with satisfactory results.

TABLE 2.—Nutrient levels in parts per million

	WP	2WP
Nitrates.....	400	600 plus
Ammonium.....	25	50
Phosphorus.....	25	40
Potassium.....	100	200
Calcium.....	125	200

After the solution is tested, it is necessary to make additions of the deficient nutrients. The amounts of chemicals per 1,000 gallons of water to provide definite parts per million are as follows:

- 7 pounds of calcium nitrate provide 130 parts per million of calcium and 400 parts per million of nitrates.
- 4½ pounds of sodium nitrate provide 400 parts per million of nitrates.
- 5 pounds and 13 ounces of potassium nitrate provide 250 parts per million of potassium and 400 parts per million of nitrates.
- 1¾ pounds of Uramon (urea) provide 90 parts per million of nitrogen equivalent to 400 parts per million of nitrates.
- 5 pounds of potassium chloride provide 250 parts per million of potassium.
- 5 pounds of potassium sulfate provide 250 parts per million of potassium.
- 1 pound of ammonium sulfate provides 28 parts per million of ammonia.
- 4½ pounds of magnesium sulfate provide 50 parts per million of magnesium.
- 2½ pounds of monocalcium phosphate provide 42 parts per million of calcium and 65 parts per million of phosphorus (200 parts per million of phosphate).
- 5½ pounds of 16 per cent superphosphate provide 65 parts per million of phosphorus (200 parts per million of phosphate).
- 5 pounds of calcium sulfate provide 145 parts per million of calcium.

During favorable growing seasons for the various crops, the full amount of ammonium sulfate is sometimes added every other week, but since the ammonium is quickly converted to nitrate, this practice may develop undesirably high nitrate levels. If such levels develop, less frequent additions should be made.

The water level in the tank is fully as important as the nutrient level and should be checked daily.

pH

The pH of the solution should be checked twice a week without fail. It should be maintained at 6.5 for most crops. Gardenias do best at a pH of 5.5 to 6. Sweet peas, stocks, carnations, gerbera, feverfew, asters, pansies, chrysanthemums, and others will grow satisfactorily in a pH of 7.

To raise the pH, a stock solution of 2 ounces of sodium or potassium hydroxide to a gallon of water should be used, or ammonium hydroxide and water, one part to three, respectively, can be used. To lower the pH, a stock solution of 1 ounce of either concentrated sulfuric or phosphoric acid to a gallon of water should be used.

When any materials are added to a solution, thorough stirring is necessary to obtain proper mixing.

AERATING SOLUTIONS

Preliminary tests on roses have indicated the desirability of aerating the solutions at intervals. Aerating can be accomplished by connecting to the inlet pipe a small pipe which leads back above the solution in the tank. A small spray nozzle should be connected at the end of the small pipe. When the solution is pumping into the bench, part of it passes into the small pipe and is sprayed from the nozzle back into the tank (fig. 15). This process aerates the nutrient solution.

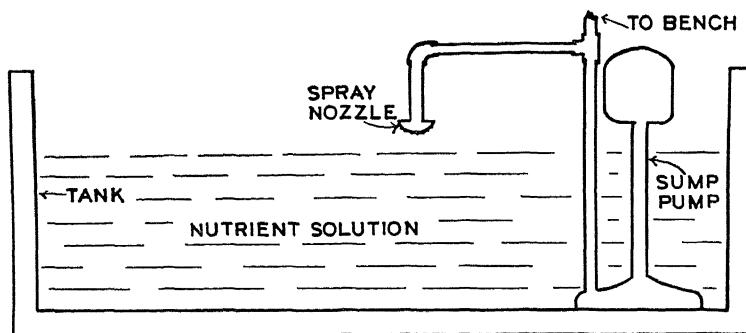


Fig. 15.—Diagram of a solution aerator

PUMPING

The number of times per day the solution should be pumped depends on the type of medium, season, size of plants, and the concentration of the solution. In summer, mature rose plants in a coarse ($\frac{1}{2}$ - to $\frac{3}{4}$ -inch) medium should be pumped three to four times during the daylight period (7 a. m., 11 a. m., 2 p. m., and 5 p. m.). In winter, pumping should be reduced to once daily or once every 2 days. Carnations should rarely be pumped more than twice daily in summer and once in 2 or 3 days in winter, providing no wilting occurs. Young plants which are not established should be pumped less frequently, as root action is slow. Experience is the best guide, together with a close check of the growth of the plants.

The concentration of the solution exerts some influence on the number of times the bench is pumped per day. The greater the concentration of the solution, the greater the number of pumpings required; and the lower the concentration of the solution, the fewer the number of times the bench is pumped per day. A WP solution would be pumped less frequently than a 2 WP solution on the same crop in the same season of year. During the heat of summer, it will be necessary to pump a WP solution frequently because of the danger of wilting. The reason for the influence of the concentration upon the number of

pumpings is not entirely clear, but it appears that greater concentrations inhibit water absorption, and unless the solution is pumped more frequently, growth is checked severely.

The solution should be pumped to within 1 inch of the surface of the medium to prevent the growth of algae (green scum). Night pumping is not essential.

PLANTING

Tests during the past 4 years have shown that for the majority of crops, planting with a soil ball may lead to serious difficulties from root and stem rots. The best practice is to sow the seed in either soil or sand and transplant the seedlings to their permanent place in the bench when they are large enough to handle. The fewer the number of times the small plants are transplanted, the more satisfactory is their growth. It is not desirable to transplant seedlings to the bench, setting them closely, and later move them to their permanent planting distance. Although space is saved by this practice, there is a severe check to the growth of the plant. Crops grown from cuttings can be benched after they are well rooted in the propagation bench.

Although the practice of benching plants out of small pots is not recommended, with such plants as grafted roses and the like, it is not always desirable to wash the soil from the roots because of the injury to the root system. Plants can be set in the medium in a V-bottom bench with a ball of soil out of 2- to 3-inch pots providing the plants are well established and show the presence of a well-developed, active root system on the surface of the soil ball. The roots spread rapidly into the inert medium, and no check in growth is observed, such as occurs when the soil is washed off. If drainage is poor, this planting practice is dangerous, especially with soft-stemmed crops, such as snapdragons and chrysanthemums, since they rot easily. The soil does not dissolve into the medium but remains intact and is removed when the plants are pulled out. Planting a portion of the bench with a soil ball on the roots and the remaining portion with bare-root plants is not recommended because of the differences in their moisture requirements. Bulbs are planted so that their "noses" are one-half inch below the surface of the medium. Too deep planting results in rotting, which can be partially overcome by less frequent pumping. Plants should be spaced in gravel similarly to the way they are in soil. Large seed (sweet peas) can be sown directly in the medium.

PEST CONTROL

Since the media do not contain any organic matter which would act as a buffer, it is necessary with some spray materials to flood the bench with tap water during the spraying operation. This water is discarded after spraying. Spray materials containing thiocyanates, particularly Loro, Lethane, and R. S. 380, will injure the roots and cause a check in growth. With most other spray materials and fumigants, it is necessary only to flood the bench with the nutrient solution just prior to spraying. The films of solution remaining on the roots and particles of the medium are sufficient to dilute the spray enough to prevent injury. If in doubt, it is best to fill the bench with tap water, spray, and discard the water. If the nutrient solution is to be changed, it should be pumped into the bench, the plants should be sprayed, and the solution discarded by manipulation of the valves as described previously. It is advantageous to run a permanent water line to the half-tile in the bench so that the

bench can be flooded for spraying by opening a valve as shown in figures 9 and 16. Sulfur sprays or dusts lower the pH. Cyanide fumigation and nicofume fumigation are safe. For sterilization purposes, copper or mercury compounds

should be avoided, as toxicity is apt to result from their use. Insects in the medium can be controlled by flooding the bench to float the insects and then spot-fumigating with nicofume pressure fumigators. Fulex (naphthalene vapor) fumigation is reported to be safe, and it is recommended that the bench be flooded with the nutrient solution during fumigation to prevent root injury.

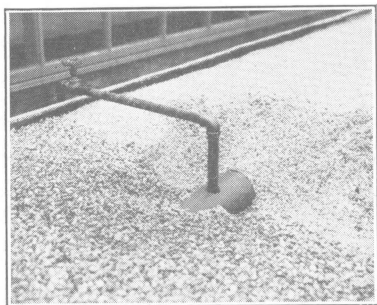


Fig. 16.—A method of flooding a bench with tap water prior to spraying

SPECIFIC CROPS

To test the effectiveness of growing crops in gravel, the most important greenhouse flowering crops have been grown from 1937 to the present time.

They included roses, carnations, chrysanthemums, gardenias, snapdragons, sweet peas, lilies, iris, narcissi, asters, stocks, euphorbia, Boston yellow daisies, pansies, feverfew, annual chrysanthemums, calendula, dahlias, bachelor buttons, and others. A report of these tests has been given by Laurie and Kiplinger (11). Changes have been brought about by newer methods and improved techniques.

ROSES

Commercial culture.—Dormant-budded or started-eye plants should be benched, preferably in January or February. Own-root stock grown for 1 year in a cloth house, stored in a cooler, and cut back similarly to a started-eye, can be benched at this time. Holding such plants in storage for later benching is detrimental, as the growth that is made is usually unsatisfactory. Because the removal of plants during the winter often upsets the grower's rotation, either grafted or small actively growing own-root stock may be used. The ball of soil on such plants should not be larger than 3 inches, or poor root action will result from such a large volume of soil in the bench.

Irrespective of the type of plant used, the starting solution should be a $\frac{1}{2}$ WP until the root system begins to develop into the medium. Pumping once in 2 or 3 days during the dark days of winter for the dormant-budded or started-eye plants is sufficient until foliage develops concurrent with the development of a larger root system. Plants benched with a ball of soil should also be pumped infrequently to allow for the development of the roots from the surface of the soil ball into the medium. Too frequent pumping causes poor root action due to the soggy soil ball.

As the plants become well established, pumpings should be increased and the concentration of the solution raised to a WP level. During the good growing seasons, spring and fall, a 2 WP solution can be used. In the warm days of summer, a WP solution pumped three to four times daily gives best results.

With the dark days of winter, the solution concentration can be reduced to a WP nitrogen level, but a 2 WP level of all other components. Such a practice of manipulation reduces the amount of blind wood and thin shoots produced.

Various solutions and media.—One of the earliest tests with roses was made to determine the effectiveness of several recommended solutions and several media. Dormant-budded “started-eye” plants of Better Times roses were used in this test. They were planted in February 1938. Table 3 shows the production record for 1 year. It will be noted that soil-grown roses produced fewer flowers per plant and poorer grade flowers than those grown in silica gravel or cinders. The differences between solutions used were not significant, but the differences between cinders and the two grades of silica gravel were significant.

TABLE 3.—The production of Better Times roses in various nutrient solutions Planted February 1938. Recorded to February 1939

Nutrient solution	Medium	Flowers per plant	Per cent by grade								
			Shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches	27 inches	30 inches
.....	Soil.....	13.0	13	48	19	10	7	2	1	.....	.....
2 E*	Silica gravel ...	19.5	11	33	28	17	6	5	.....	.....	.....
2 WP*	Silica gravel ..	22.0	4	20	31	22	14	6	2	.....	1
2 W*	Silica gravel	20.0	3	14	23	25	19	9	6	.....	1
2 WP	Fine silica gravel.	17.5	7	19	24	28	12	6	4	.....	.....
2 WP	Coarse cinders ..	26.0	2	10	24	22	24	12	6	.....	.....

*For composition of the solution see Appendix tables I and II.

Potassium additions.—Since high potassium content is usually recommended for optimum growth and production of roses, a test was made in 1939 to determine the effectiveness of potassium additions. Table 4 shows the effect of increasing the potassium content of 2 WP solution on the production of Lucile Hill rose. It will be noted that again, as in table 3, the production in gravel is higher than in soil and that an increase in the potassium content of the 2 WP solution increases the production over that in the regular 2 WP solution significantly. The WP solution ratio of nitrogen to potassium is about two to one, and it is possible that a change to approximately a one to one ratio might increase the rate of stored carbohydrate utilization during the night and result in the development of a greater number of shoots per plant.

TABLE 4.—The effect of increasing the potassium content in the nutrient solution on the production of the Lucile Hill rose

Treatment	Flowers per plant	Per cent by grade					
		Culls and shorts	9 inches	12 inches	15 inches	18 inches	21 inches
2 WP	17.0	14.7	36.3	30.4	12.7	4.9	1.0
2 WP plus 500 parts per million of potassium	21.3	16.4	36.7	26.6	13.3	4.7	2.3
Soil	12.8	15.8	40.8	27.9	11.7	3.3	.4

Glucose additions.—In an attempt to supply additional carbohydrates to roses during cloudy winter weather, Better Times and Happy Days roses were supplied with glucose solutions at concentrations of 1.3, 2.6, and 4.1 per cent.

No differences in growth could be observed, but considerable difficulty was encountered because of increased bacterial activity at the roots and a subsequent check in growth. This activity was finally controlled by additions of silver as silver nitrate at the rate of one to two parts per million.

Trace element additions.—Some workers have recommended the additions of such trace elements as boron, copper, and zinc to nutrient solutions to secure greater growth and development of plants. Table 5 shows the results of such treatments on the Better Times rose. It will be noted that some increases in production were observed from addition of boron and zinc in low concentrations. The additions of copper proved to be detrimental. Since the materials composing the nutrient solutions are commercial in form, they frequently contain some of the trace elements; hence, under such conditions, any additions may be unnecessary and sometimes even detrimental. Certain white varieties of roses, such as Snow White and American Pride, are benefited by additions of boron up to five parts per million.

Occurrence of trace elements.—A WP solution with recommended additions of ferrous and manganous sulfates was flushed through C grade Haydite, and a 500-cubic centimeter sample was taken for spectrographic analysis. Although the relative amounts of the mineral elements present cannot be determined accurately by this method of analysis, minute quantities can be detected readily. The following minerals were found in their estimated order of decreasing concentration: calcium, potassium, magnesium, silicon, sodium, iron, aluminum, titanium, copper, manganese, and vanadium. With the presence of these trace elements in the solution, either from the fertilizer-grade chemicals or the Haydite, their addition would appear unwarranted unless a deficiency occurs.

TABLE 5.—The effect of various concentrations of boron, copper, and zinc on the production of Better Times roses

Planted January 2, 1939. Recorded to August 8, 1939

Additional treatment	Basic solution	Flowers per plant	Per cent by grade						
			Culls and shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches
1 part per million of boron (later 5 parts per million) ...	2 WP	14.7	14.8	19.3	29.6	21.6	11.4	2.3	1.1
2 parts per million of boron (later 10 parts per million) ..	2 WP	14.2	7.1	32.9	23.5	28.2	7.1	1.2	.....
1 part per million of zinc (later 10 parts per million) ..	2 WP	14.7	4.6	36.4	30.7	21.6	4.6	2.3	.....
2 parts per million of zinc (later 50 parts per million) ..	2 WP	15.3	34.8	45.7	15.2	4.4	.....	.....	.....
1 part per million of boron and zinc (later 5 and 10 parts per million, respectively)	2 WP	16.3	21.4	39.8	21.4	12.3	5.1	.....	.....
2 parts per million of boron and zinc (later 10 and 50 parts per million, respectively)	2 WP	11.3	20.6	38.2	32.4	5.9	2.9	.....	.....
.....	Ohio 4*	10.3	6.5	24.2	25.8	21.0	11.3	6.5	4.8
56 parts per million of ammonia added weekly	2 WP	10.7	9.4	10.9	35.9	14.1	17.2	9.4	4.7
Check plot	2 WP	12.0	6.9	29.2	27.8	23.6	8.3	4.2	.....
1 part per million of copper (later 25 parts per million) ..	2 WP	10.5	20.6	31.8	19.1	17.5	9.5	1.6	.....
.....	2 W	8.5	11.8	23.5	29.4	19.6	9.8	5.9	.....

*For composition of the solution see Appendix tables I and II.

Sources of nitrogen.—The source of nitrogen has been a controversial subject for many years. In our work, an attempt was made to determine the correlation between the plant growth during the winter months and the source of nitrogen supplied in the nutrient solutions. A WP solution with potassium nitrate and ammonium sulfate was used as a control, and the following chemicals were used alone as a source of nitrogen: ammonium sulfate, ammonium nitrate, sodium nitrate, and calcium nitrate. Each material was substituted in the original WP solution in amount equivalent to a 400 parts per million nitrate nitrogen level.

Nitrate tests during the months of November and December indicated an accumulation of nitrates in the solutions containing high ammonium which reached its peak 15 to 18 days after the application of the solutions. A comparison of the results of the use of ammonium sulfate and ammonium nitrate showed that the peak of nitrate accumulation was reached when all the ammonium disappeared from the solutions.

The growth of rose plants in the ammonium nitrate solution practically stopped when the pH reached 5.5 or lower. The same was true in the ammonium sulfate plot. The injury did not manifest itself upon the roots, but produced a yellowing of foliage, an almost complete drop of leaves, and subsequent failure of new axillary buds to develop. It may be assumed that the high hydrogen-ion concentration of the solution indirectly affected the nitrate reduction process and the ammonium accumulation.

Time of planting.—The usual procedure in commercial rose growing is to plant dormant-budded stock from January until April or May. Since the vitality of such stock is depleted in storage, a test was made to determine the comparative production between Happy Days roses planted in January and similar roses kept in storage at 40° F. and planted in March. Table 6 shows a very significant difference in favor of the earlier planting.

TABLE 6.—A comparison of 1 year's production of Happy Days roses at 60° F. planted in January and March

Medium	Planting date	V-bottom bench			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Silica gravel.....	March 22, 1939	10.4	2.3	14.4	83.3
FF Haydite.....	March 22, 1939	14.8	8.3	27.2	64.5
C Haydite.....	March 22, 1939	11.0	13.5	15.1	71.4
C Haydite.....	January 22, 1939	36.1	21.9	15.9	62.2

Planting with a ball of soil versus bare roots.—Grafted or "own-root" roses are grown on in pots before planting in soil. The same may be done with dormant-budded plants if they are to be held until late spring or summer planting. In gravel culture the original procedure was to wash the soil off such plants for fear of detrimental effects from inclusion of the soil in the inert media. Since the removal of the soil results in a definite check in initial growth due to the destruction of many of the root hairs, a series of tests was made to determine whether planting with a ball of soil was feasible. Table 7 indicates that such a procedure is not detrimental and that it may even result in higher production due to quicker starting of growth.

TABLE 7.—The effect of planting roses with and without a ball of soil on the production of two varieties

Variety	Treatment	Flowers per plant	Per cent by grade									
			Culls	Shorts	9 inches	12 inches	15 inches	18 inches	21 inches	24 inches	27 inches	30 inches plus
Mrs. F. D. Roosevelt	Soil ball intact . .	21.0	4.8	3.2	19.8	26.2	18.3	14.3	7.1	3.9	1.6	0.8
	Soil ball removed.	16.5	9.1	9.1	18.2	32.3	21.2	9.1	1.0	.....	.....	.....
Talisman	Soil ball intact ...	10.8	.0	3.1	13.8	33.8	21.5	18.5	6.2	3.1	.....	.....
	Soil ball removed.	9.8	5.1	3.4	15.3	30.5	28.8	13.5	3.4	.....	.....	.....

“Drying off” versus cutting back gradually.—The commercial rose grower rests his roses during the summer by the simple process of reducing the moisture at the roots for a week or two and then cutting the plants back, or he may reduce the moisture in the soil slightly and gradually cut his plants back stem by stem until a short, uniform height is obtained. In gravel culture, similar results can be obtained by withholding the solutions during the “drying” periods. After several different tests have been made, the results show that the following procedure is desirable: When the roses are ready for the rest period in the summer, the solution is withheld until the more succulent stems show signs of wilting, usually in about 3 days. At that time, the medium is flushed with clear water to bring about turgidity, and again the solution is withheld until wilting. A repetition of this drying will result in a rest period of 9 or 10 days. Then a $\frac{1}{2}$ WP solution is applied until new root action develops. If gradual cutting back is desired, it can be done similarly to the process in soil by reducing the number of pumpings of the solutions. The results of these tests showed that production was similar with either method.

Red spider control.—To avoid the necessity of using spray materials, tests were made to determine the efficiency of the monthly inclusion of selenium in the solution as a toxic agent to mites. Chemically pure sodium selenate (Na_2SeO_4) was used at concentrations of selenium varying between $2\frac{1}{2}$ to $12\frac{1}{2}$ parts per million on Better Times and Peter's Briarcliff roses. The higher concentrations provided up to 47 per cent control, which is insufficient for practical purposes. Pyrethrum, timbo, and derris were ineffective when applied in solutions at 0.025 per cent.

Production.—The usefulness of such a new process as growing roses in gravel depends upon a profitable production. In table 8 are the results of a 2-year test in which a number of commercial varieties were grown on a sufficiently large scale to make results significant. These roses were “carried through” in the usual commercial manner by cutting back gradually with a knife during the late spring season. Very little pinching was practiced, and with the maintenance of a high humidity, especially during the spring and summer, the production of flowers per plant and the number of flowers with stems over 12 inches long are exceptionally high. In many cases the differences between soil and gravel are significant, and the production in soil is equal to that of the average commercial grower. Lowered production in the modified

TABLE 8.—A comparison of 2 years' average production of roses in flat and V-bottom benches in soil and V-bottom benches in gravel

Planted February 1, 1940; recorded to February 1, 1942

Variety	Type of plant	Soil, V-bottom bench				Haydite, V-bottom bench				Haydite, modified V-bottom bench				Soil, flat-bottomed bench			
		Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus	Flowers per plant	Per cent culls and shorts	Per cent 9 to 12 inches	Per cent 12 inches plus
Better Times..	Own root	27.8	4.2	10.4	85.4	37.4	5.1	6.8	88.1	33.5	3.9	9.8	86.3	25.5	2.7	13.1	84.2
Better Times..	Started eyes	25.4	3.1	5.3	91.6	36.4	4.3	7.6	88.1	28.4	3.5	7.2	89.3	34.2	2.7	8.6	88.7
Better Times.	Grafted	23.7	2.8	7.0	90.2	32.9	2.0	4.5	93.5	.....	.....	.....	... ..	25.1	3.2	11.6	85.2
Happy Days..	Started eyes	24.7	6.2	6.6	87.2	37.8	6.8	6.6	86.6	.....	.....	.....	.....	30.0	6.9	8.3	84.8
Peter's Briar-cliff.....	Started eyes	22.5	3.4	4.0	92.6	34.5	7.1	5.9	87.0	25.2	7.2	8.8	84.0	27.9	6.9	8.9	84.3
Lucile Hill....	Started eyes	23.3	1.1	6.9	92.0	35.5	1.2	8.7	90.1	24.4	1.1	10.2	88.7	30.2	.4	7.1	92.5
Joanna Hill....	Started eyes	23.4	.7	5.7	93.6	29.9	1.1	5.6	93.3	23.6	.3	2.5	97.2	31.4	1.4	7.7	90.9

TABLE 9.—A 3-year comparison of the production of flowers per plant of roses in flat and V-bottom benches in soil and V-bottom benches in gravel
Planted February 1, 1939; recorded to February 1, 1942

Variety	Type	Soil, ground bench, deep V-bottom			Haydite, deep V-bottom			Haydite,* modified V-bottom			Soil, raised bench, flat bottom		
		1939-1940	1940-1941	1941-1942	1939-1940	1940-1941	1941-1942	1939-1940	1940-1941	1941-1942	1939-1940	1940-1941	1941-1942
Better Times.....	Own root	12.6	25.1	20.6	31.8	38.0	36.8	23.5	27.2	39.7	13.7	27.4	23.6
Better Times.....	Started eyes	15.9	25.7	25.1	29.3	35.7	37.1	22.6	24.8	31.9	15.4	32.3	36.1
Better Times.....	Grafted	15.8	25.3	22.0	25.5	32.5	33.3	.....	.....	.....	13.5	26.6	23.5
Happy Days.....	Started eyes	14.5	25.5	23.0	28.2	38.0	37.5	.....	.....	.....	16.3	30.3	29.8
Peter's Briarcliff	Started eyes	12.6	23.2	21.7	23.6	33.9	35.0	24.5	21.3	29.1	14.9	30.6	25.3
Lucile Hill.....	Started eyes	15.1	24.2	22.5	32.1	35.7	35.4	29.9	24.9	23.9	14.8	32.5	27.8
Joanna Hill.....	Started eyes	15.8	25.3	22.5	35.9	29.9	29.8	24.4	19.4	27.7	16.4	33.1	29.6

*Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940. Plants were removed, stored at 40° F. for 3 weeks, and replanted on February 21, 1940. This operation accounts for the lowered production in this bench for the period during 1940-1941.

V-bottom bench was due to exceptionally heavy pruning and a 3-week storage period at 40° F. during the time the existing flat-bottomed bench was converted to a modified V-bottom with a slope of 1½ inches from side to center.

Flowers per plant.—Table 9 shows a 3-year production record of a number of different commercial varieties grown on a large scale. It will be noted that the production during the third year does not decrease in gravel culture as compared with soil. Usually in the average commercial rose range, the decrease in soil is greater than that which occurred in our tests. This maintenance of high production is undoubtedly due to better aeration of the gravel medium over that of the soil. The decrease in the production of flowers by the plants in Haydite in the modified V-bottom bench from 1940-1941 was due to the presence of solution standing on the bench bottom before the bench was converted from a flat bottom to a modified V. The conversion was made in February 1940, and the plants were stored for 3 weeks at 40° F. during the alteration.

In table 10 is shown the average of the 3 years' production for the plants in table 9. It is clear that plants grown in gravel culture averaged higher in production than similar plants in soil. The differences were striking in both tables 9 and 10, yet the production in soil would equal that of the average grower.

TABLE 10.—A comparison of a 3-year average production of flowers per plant of roses in flat and V-bottom benches of soil and V-bottom benches in gravel

Planted February 1, 1939; recorded February 1, 1942

Variety	Type	Soil, ground bench, deep V-bottom	Haydite, deep V-bottom	Haydite,* modified V-bottom	Soil, raised bench, flat bottom
Better Times.....	Own root	19.4	35.5	30.1	21.5
Better Times.....	Started eyes	22.2	34	26.4	27.9
Better Times.....	Grafted	21	30.4	.....	21.2
Happy Days.....	Started eyes	21	34.5	.....	25.5
Peter's Briarcliff	Started eyes	22.5	30.8	24.7	23.6
Lucile Hill.....	Started eyes	20.6	34.4	26.2	25
Joanna Hill.....	Started eyes	21.2	31.8	24.1	26.3

*Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940.

Seasonal average.—One of the numerous cultural difficulties with roses in soil is the slowing down of the productiveness of the plant during the winter months. Tests were run over a 2-year period to compare the seasonal production of several commercial varieties in both soil and gravel culture. The months selected for the seasons were as follows: for spring—March, April, and May; for summer—June, July, and August; for fall—September, October, and November; and for winter—December, January, and February. The results of this test are shown in table 11.

The production of flowers by the plants does not slow down in winter in gravel culture any more than in soil. In fact, the increase in production with the gravel-grown plants holds its proportion to the soil over the entire yearly period. Table 11 also indicates that in central Ohio with both soil and gravel culture, approximately one-third of the production is obtained between November and April, at which time the greatest economic returns for roses are secured.

TABLE 11.—A comparison of the production in flowers per plant of roses in soil and gravel culture during various growing seasons
Planted February 1, 1940; recorded to February 1, 1942

Variety	Type	Soil, ground bench, deep V-bottom				Haydite, deep V-bottom				Haydite,* modified V-bottom				Soil, raised bench, flat bottom			
		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Better Times.....	Own root	4.3	7.4	7.4	3.6	6.6	12.6	12.5	5.6	7.2	11.4	12.4	5.9	3.4	8.5	8.4	3.3
Better Times.....	Started eyes	4.9	7.9	8.4	4.1	6.0	12.4	12.6	5.3	5.7	9.9	9.7	5.8	4.2	10.1	9.2	4.0
Better Times.....	Grafted	4.4	7.6	7.8	3.8	6.3	11.6	10.0	4.9	.....	.....	.....	.....	3.6	9.7	9.1	4.1
Happy Days.....	Started eyes	4.7	7.7	8.4	3.4	6.5	13.0	12.8	5.4	.....	.....	.....	.....	4.4	11.2	10.6	3.9
Peter's Briarcliff ..	Started eyes	4.2	7.1	7.3	3.9	5.9	11.6	11.1	5.7	4.2	8.9	8.9	5.3	3.3	10.5	9.3	4.5
Lucile Hill.	Started eyes	3.6	7.5	8.3	3.8	5.6	11.8	12.9	4.8	4.9	10.6	11.5	5.3	3.5	11.3	10.1	4.4
Joanna Hill	Started eyes	3.3	9.3	8.2	3.1	3.9	11.9	9.6	3.9	4.8	9.3	7.9	3.2	4.1	14.6	11.3	4.2

*Bench changed from a flat bottom to a modified V-bottom (1½-inch slope from side to center) in February 1940.

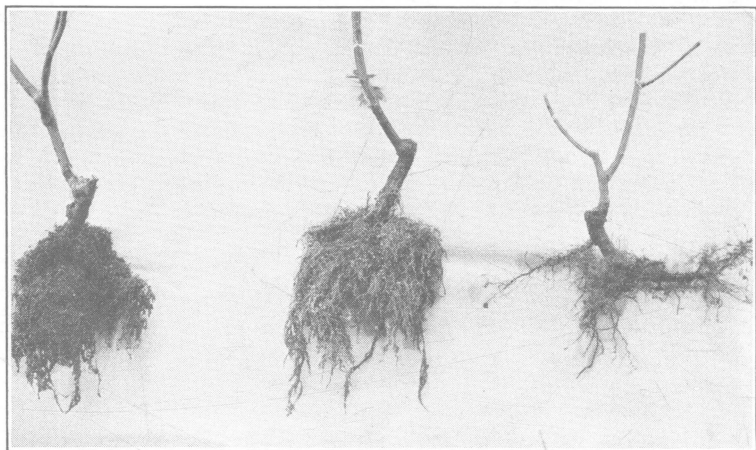


Fig. 17.—Root systems of Better Times roses. Left to right—WP in cinders, WP in silica gravel, soil

Drainage in benches.—Reference has been made to the conversion of an existing flat-bottomed bench to a modified V-bottom. It was found that roses grown in flat-bottomed benches were not equal in growth and production to those grown in V-type benches. Careful examination disclosed that irregularities of the floor of the flat-bottomed bench made perfect drainage of the solution back into the tanks impossible (fig. 13). In the V-type bench, any standing solution remains under the half-tile in the center and does not come in contact with the roots. Emphasis of this feature resulted in greater perfection of growth in several commercial establishments where recommendations for the change were followed.

Temperature relations.—Many varieties of roses are usually grown at a night temperature of 58 to 60° F. It has often been suggested, however, that at lower temperatures, such varieties as Better Times, Peter's Briarcliff, Joanna Hill, and others would produce better quality but fewer flowers per plant. Since a difference of 3 to 5° F. means a considerable saving in fuel, tests were made to determine whether or not lower temperatures of the air combined with warming of the solution would produce responses comparable to those obtained by growing such roses in the higher temperature. One house was held at the usual night temperature of 60° F., and the other house was held at a night temperature of 56° F., but the solution was maintained at 85° F. When this solution was pumped into the bench, it dropped to a temperature of 70° F. No appreciable differences in production or quality were obtained.

Zinc toxicity.—Symptoms of zinc toxicity were observed in roses whenever galvanized stakes used for support were inserted into the medium. Painting of inserted ends with emulsified asphalt eliminated this difficulty.

Leaf drop.—Frequently in both soil and gravel, the check in growth brought about by defoliation of varying severity is serious. Although no effective preventives of leaf drop have been developed, observance of several

precautionary measures will minimize its injurious effects. Unnecessary variations in moisture of the medium which make it either too wet or too dry bring about leaf drop from the loss of roots. Mulching roses in gravel culture in hot weather with sphagnum moss, excelsior, glass wool, or some other relatively inert material may aid in preventing excessive leaf drop. Maintenance of high humidity during spring and summer prevents rapid fluctuations in the moisture content of the plant and the medium and also results in longer stemmed flowers. Shading the glass during spring and early summer aids in the maintenance of humidity, as well as in reducing the temperature.

CARNATIONS

Commercial culture.—The growing of carnations in gravel presents comparatively few difficulties. The plants can be grown in the field and benched in July or August. The loose soil should be shaken off and the plants benched with the small amount of soil that will adhere underneath the crown. Pumping should be reduced to a minimum at this initial stage to prevent the soil from becoming too moist and causing stem rot. Plants can be handled in the greenhouse throughout their entire cycle of growth. Rooted cuttings should be placed close together in the bench in gravel and transplanted to their permanent places in May or June. The retention of a small soil ball is not objectionable.

TABLE 12.—Production of two carnation varieties in soil, cinders, and silica gravel

Planted in August and cropped till following May

Variety	Flowers per plant			Stem length, inches			Flower diameter, inches		
	Soil	Coarse cinders	Silica gravel	Soil	Coarse cinders	Silica gravel	Soil	Coarse cinders	Silica gravel
Mallow Pink ..	11	12	14	20	22	20	3.0	3.0	3.0
Patrician	9	12	13	18	20	18	3.0	3.2	3.2

Table 12 shows the results of one test indicating insignificant differences in production, stem length, and flower diameters between soil- and gravel-grown carnations. Greater quality and stiffness of stem, however, may be expected in gravel-grown plants, provided that during the fall and winter months, pumpings are reduced to a minimum. The number of pumpings during that period will depend upon light conditions. Very satisfactory results have been secured in cinders, Haydite, or gravel with pumpings made once in 2 or even 3 days. Table 13 shows a series of solution tests. The poorest results were obtained where the balance of nitrogen and potassium was apparently improper, notably in the New Jersey, Ohio 6, and Ohio 12 solutions.

Spread of stem rot will occur as rapidly in gravel as in soil.

CHRYSANTHEMUMS

Commercial culture.—Tests with chrysanthemums have been conducted for four seasons and show in general that little difficulty will be experienced in gravel culture provided drainage of the bench is perfect. Plants may be benched with a ball or planted directly out of the propagating bench. Washing off the soil ball is inadvisable. Table 14 gives the production of two varieties

TABLE 13.—Production of carnations in C Haydite with various nutrient solutions

Nutrient solution	Puritan			Virginia			Chief Kokomo		
	Flow-ers per plant	Stem length, inches	Flower diam-eter, inches	Flow-ers per plant	Stem length, inches	Flower diam-eter, inches	Flow-ers per plant	Stem length, inches	Flower diam-eter, inches
2 WP	7.1	23.7	2.6	6.1	19.1	2.8	8.0	20.8	2.9
Ohio 6*	5.0	24.2	2.5	5.7	20.2	2.6	9.0	22.4	2.9
Ohio 10*	7.3	23.6	2.5	3.2	20.0	2.6	8.1	21.0	2.9
Ohio 11*	7.5	23.0	2.5	7.0	19.0	2.5	11.0	21.7	2.9
Ohio 12*	4.6	21.3	2.1	9.1	19.5	2.6	11.8	20.9	2.8
Ohio 13*	7.3	23.2	2.6	6.5	21.0	2.6	7.5	22.4	2.8
Ohio 15*	8.0	23.3	2.5	7.2	21.4	2.4	9.3	21.0	2.9
New Jersey...	6.8	23.6	2.7	4.5	19.2	2.5	5.7	22.3	2.8

* For composition of the solution see Appendix tables I and II.

TABLE 14.—Production of Firebird and Silver Sheen chrysanthemums in various media and nutrient solutions

Nutrient solution	Medium	Firebird	Silver Sheen	
		Ounces per plant	Stem length, inches	Flower diameter, inches
WP	Soil	3.7	39	4.5
2 WP	Silica gravel	4.2	42	5.5
2 WP*	Silica gravel	4.0	40	5.0
2 W	Silica gravel	5.9	40	5.0
2 D	Silica gravel	4.2	38	5.0
2 D	Silica gravel	4.8	41	5.0
2 D	Limestone	4.3	37	5.0
2 D	Fine calcareous gravel	3.4	35	5.5
2 D	Coarse calcareous gravel	4.5	36	5.0

* Mulched with glass wool.

grown in silica gravel, limestone, and calcareous gravel with solution variations. The differences observed between solutions and between media were not significant. The application of a mulch of glass wool reduced the rapid drying out of the medium and gave significant differences in the production of Firebird. Figure 18 shows growth of Silver Sheen in various solutions. For best results, B grade Haydite should be used.

SNAPDRAGONS

Commercial culture.—Snapdragons can be grown successfully in gravel culture if the concentration of the nutrient solution is never raised above a WP level. Plants may be benched out of 2½- or 3-inch pots, or, preferably, directly from the seed flat. Plants in pots must be well established so that the root system immediately begins to develop into the medium, or root rot will develop from the retention of moisture in the soil ball. With seedlings from the seed flat, it is desirable to add a small amount of sand, fine Haydite, or other inert material at the time of planting to prevent drying of the small root system in the coarse medium at the initial stages of growth. Plants should be started on a ¼ WP solution, which should gradually be raised to a WP level.



Fig. 18.—Silver Sheen chrysanthemums grown in soil (far left) compared with those grown in silica gravel with various solutions (remaining plants). Note the larger leaves developed in gravel.

Gravel-grown seedlings.—Growing the seedlings close together and later transplanting them to normal planting distance proved detrimental. The disturbance of the root system checked the plants so severely that they failed to produce enough stems to warrant allowing them to remain in the bench.

Ammonium additions.—It has been thought that the presence of ammonium nitrogen in the nutrient solution has an inhibiting effect upon the growth of snapdragon plants. The WP solution (28 parts per million of ammonium) and the W solution (ammonium absent) were employed to determine the influence of ammonium nitrogen in the nutrient solution on growth and production. The results, shown in table 15, fail to show any inhibiting effect from the ammonium nitrogen.

TABLE 15.—The influence of ammonium nitrogen on the production of the Christmas Cheer snapdragon

Media	Solution	Stems per plant	Stem length, inches	Spike length, inches
C Haydite	WP (28 parts per million of ammonium).	8.3	25.0	6.3
C Haydite	W (ammonium absent)	8.1	23.5	5.2
Calcareous gravel	WP (28 parts per million of ammonium).	8.8	24.1	5.5
Calcareous gravel	W (ammonium absent)	8.2	24.1	5.3

The differences between the plants grown on the WP and W solutions were small. The WP solution produced less than one stem more per plant. The differences in stem and spike length were negligible. Although the plants with ammonium were a darker bluish-green during periods of cloudy weather in winter, this color faded to normal green as the intensity and duration of sunlight increased.

GARDENIAS

Commercial culture.—The management of gardenias in gravel culture is not difficult if close attention is given to the maintenance of an optimum pH of the solution and frequent additions of iron. Gardenias grow most satisfactorily in gravel culture at a pH of 5.5-6.0. Weekly additions of iron sulfate aid in holding the pH at the desired level.

Plants may be benched in B Haydite or cinders directly from the propagation house or with a ball of soil from late April to the first of June. A $\frac{1}{2}$ WP solution should be used until root action is strong, and then the concentration can be raised to a WP level. Pumping once a day after benching and later increasing the number of flushings to prevent wilting is advised. The use of a 2 WP solution during the summer promotes strong growth. Frequent overhead syringing is necessary.

Setting buds for a Christmas crop in central Ohio is an uncertain procedure with 1-year-old plants. The house should be cooled to 58-60° F. during the night in August and early September if weather conditions permit. A reduction in the number of pumpings per day hardens the growth and favors bud setting. Raising the concentration above a 2 WP level to harden the growth and increase the setting of buds is not safe except in the hands of an expert. Too severe injury to the roots causes the development of chlorosis, which usually persists until the following spring. Overhead syringing should be reduced to a minimum during the bud-setting period, as it tends to promote soft growth.

Lowering the concentration of the solution to a WP level during the winter prevents the plants from becoming hardened. Bottom heat under the benches aids in maintaining a dark green color of the leaves during winter. The plants may be cut back in spring similarly to plants in soil. Pumpings should be reduced to compensate for the removal of foliage. When the plants begin to grow, a 2 WP solution can be used. Little difficulty will be experienced in setting a Christmas crop of buds on 2-year-old plants if the recommended practices are followed.



Fig. 19.—Root development in Belmont-type gardenias in various solutions. Left to right—2 D Purdue, 2 E Purdue, WP Ohio, and New Jersey. Note the large numbers of white roots on all except the New Jersey solution, which contained a high nitrogen level.



Fig. 20.—Root development on Belmont-type gardenias in various media with a WP solution. Left to right—silica gravel, calcareous gravel, C grade Haydite, and cinders. Poor root system on calcareous gravel due to an alkaline medium. Note the development of white roots on the other three media.

Solution variations.—Several solutions were used in C Haydite and silica gravel on gardenias. The production is shown in table 16. The WP solution was superior to either the 2 D or 2 E with *Gardenia veitchii*, possibly because of the high nitrogen levels in relation to the low phosphorus in the Purdue solutions. Belmont types were not affected by the nutrient balance; their production was slightly higher with the 2 D solution. In silica gravel, the WP solution gave higher production on both *veitchii* and Belmont-type gardenias than the New Jersey solution. The latter solution has a very high nitrogen and phosphorus content in relation to the potassium.

TABLE 16.—Production of gardenias in C Haydite and silica gravel in various nutrient solutions

Nutrient solution	Medium	Flowers per plant	
		Veitchii	Belmont type
Ohio WP	C Haydite	32.5	23.5
Purdue 2 D*	C Haydite	12.2	27.0
Purdue 2 E*	C Haydite	13.6	23.0
Ohio WP	Silica gravel	27.6	18.6
New Jersey*	Silica gravel	21.6	13.0

*For composition of the solution see Appendix tables I and II.

Production records.—Although the growing of gardenias in gravel culture may not result in significantly greater production than growing in soil, more flowers of a larger diameter were secured, as indicated in table 17. These 2-year-old plants were cut back in May 1941, and both were grown in the usual commercial manner.

TABLE 17.—The production of 2-year-old *Gardenia grandiflora*, Belmont type, in cinders and soil

Planted May 29, 1940; recorded to May 30, 1942

	Cinders	Soil
Flowers per plant	61.2	54.1
Diameter of flower, inches:		
Over 4	67.3	43.2
3 to 4	31.6	54.1
Culls	1.1	2.7

LILIES

Commercial culture.—Lilies respond satisfactorily in gravel when the bulbs are planted in the medium so that the tips are close to the surface. Since this planting practice causes longer occupation of the bench than is profitable, a new scheme was devised. The bulbs can be planted in shallow flats, watered with a WP solution, and then racked one on top of another in any cool place or under a bench. It is necessary to maintain a uniform moisture content of the medium in the flat by additional applications of the WP solution. As soon as growth of the tops developed, the flats were plunged into benches filled with inert medium, and the benches were then pumped regularly. Table 18 shows the results of such treatment.

TABLE 18.—Lily production in gravel culture at 50° F.

Type		Flowers per stem	Stem length, inches	Number of days to mature
<i>L. Giganteum</i>	Benched December 6	5.1	33	150
<i>L. Erabu</i>	Benched January 12	5.8	32	101
<i>L. Erabu</i>	Flatted February 7 Benched February 28	4.9	33	93
<i>L. Erabu</i>	Flatted March 9 Benched March 29	3.5	32	97

In general, stronger stems and larger flowers can be expected from plants grown in gravel than from those developed in soil.

Production.—Table 19 shows the results of successive plantings of southern- and northern-grown *Lilium giganteum*. These bulbs were planted directly in the bench and pumped with a WP solution. It will be noted that only insignificant differences appear between gravel- and soil-grown plants (fig. 21).

TABLE 19.—Production of lilies in soil and various media in nutrient solutions

Date planted	Type	Medium	Salable flowers per stem	Blasted flowers per stem	Stem length, inches	Days to maturity
February 15 ...	Southern	Soil	4.0	0.5	24.0	109
	Southern	Silica gravel.....	4.8	1.3	32.0	105
	Northern	Soil.....	2.8	.3	21.0	109
	Northern	Silica gravel.....	3.0	.5	28.0	105
March 30	Southern	Soil.....	2.5	.0	20.0	84
	Southern	Silica gravel.....	3.0	.3	20.5	84
	Northern	Soil.....	1.6	.0	17.0	84
	Northern	Silica gravel.....	1.6	.0	17.5	84
April 18	Southern	Soil.....	2.1	.1	20.0	75
	Southern	Silica gravel.....	3.0	.2	27.5	75
	Southern	Cinders	3.2	.3	28.5	75
	Southern	Limestone.....	2.8	.1	28.5	75
May 16	Southern	Soil.....	2.0	.0	23.0	70
	Southern	Silica gravel.....	2.3	.0	24.5	69

STOCKS

Commercial culture.—Stocks can be grown successfully in gravel, but careful attention must be given to several details. Seed can be sown directly in the bench, and the plants later thinned to reduce spindly growth. The plants removed in the thinning process should not be used as additional planting material, because they usually fail to grow in a satisfactory manner, probably because of injury to the roots. Although direct seeding causes a long period of occupation of the bench, it can be used if a sprinkling of some fine material, such as sand or AAA Haydite, is placed in the row for the seeds to aid in maintaining moisture for germination and early growth. Transplanting with a ball of soil may lead to considerable root and stem rot if the plants are not well established at the time of benching. With several pumpings per day, the soil ball becomes soggy, and new roots may fail to develop into the medium

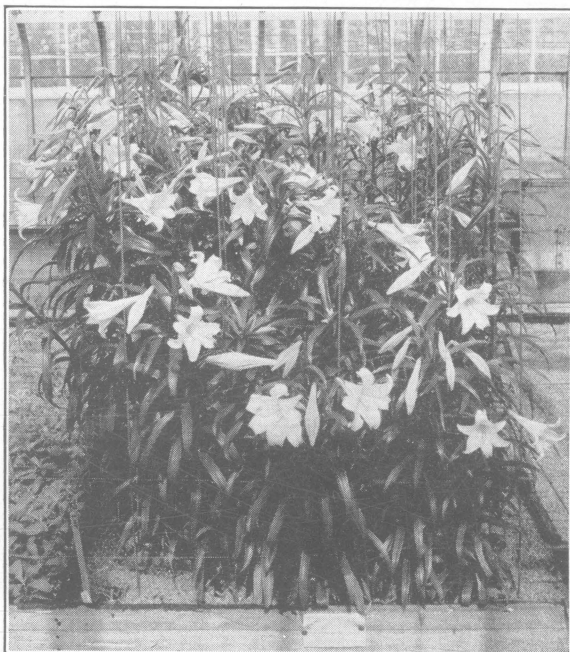


Fig. 21.—Lilies in silica gravel

surrounding the ball. If the plants are not well established in pots, the soil becomes poorly aerated from pumping of the nutrient solution, and death of the roots and plant will result. When the crop is mature, the soil ball is readily removed by pulling the stem of the plant out of the medium, as the soil ball remains practically intact. With most crops, the roots that remain in the medium are insufficient to cause later complications.

Removal of the soil ball.—Several varieties of stocks were grown with a WP solution in a V-bottom bench containing silica gravel. Previously, the young plants had been grown in 2½-inch pots, and some were transplanted with the ball of soil removed by washing in water. On others, the soil ball remained intact and was set in the gravel so that one-half inch of gravel covered the surface of the ball of soil.

TABLE 20.—The effect on stem length of transplanting stocks with and without a ball of soil

Variety	Treatment	Number cut		Stem length, inches
		Singles	Doubles	
Gardenia	Soil ball intact	10	12	32.6
Gardenia	Soil ball removed	10	5	29.7
Rose Pink	Soil ball intact	21	26	31.3
Rose Pink	Soil ball removed	15	14	28.5
Lilac Lavender	Soil ball intact	20	32	32.0
Lilac Lavender	Soil ball removed	11	14	29.3

Comparison of soil and gravel.—Before it was discovered that complete drainage was necessary, many experiments were conducted to determine the comparative production of plants grown in gravel culture and in the commercial manner in soil. The results on stocks grown in a flat-bottomed bench in a WP solution are shown in table 21.

TABLE 21.—Production of Lilac Lavender stocks in soil, cinders, and silica gravel

Medium	Number cut		Stem length, inches	Spike length, inches
	Doubles	Singles		
Soil.....	36	60	16	4.5
Cinders.....	52	54	22	5.5
Silica gravel.....	51	54	19	6.0

In spite of the adverse conditions of poor drainage, longer stems and flower spikes were obtained in nutrient solutions than in soil.

SWEET PEAS

Commercial culture.—Of the various methods of germinating the seeds of sweet peas, none was more satisfactory for fall and winter sowing than planting the seeds in the row about 1 to 1½ inches deep directly in the medium in which they were to be grown. The medium was then flooded with a ½ WP solution and kept slightly on the dry side until the young plants appeared. Too dry a medium will result in death of plants from desiccation, and a wet medium promotes rot. Pumping is increased to two periods per day after the plants show signs of vigorous growth. Summer sowing of peas has been variable in results, and it is assumed that the medium becomes too dry and hot, so that the young plants wither quickly. A mulch of excelsior may overcome this difficulty. Manipulation of nutrition during cloudy winter weather is easily accomplished by varying the amounts of the different elements in the solution.

Comparison of soil and gravel.—Difficulties encountered in the commercial culture of sweet peas in soil are numerous. Production data compiled in table 22 show that there is an advantage in growing sweet peas in gravel. Increasing the concentration of the nutrient solution to the 3 WP level caused a drop in production and shortening of the stems. The highest production and best quality were obtained by the use of a 2 WP concentration.

TABLE 22.—The effect of growing sweet peas in calcareous gravel with various nutrient solutions

Nutrient solution	Stems per foot of row
Soil.....	144
WP.....	150
2 WP.....	178
3 WP.....	140
New Jersey (carnation)*.....	163
2 D*.....	158

*For composition of the solutions see Appendix tables I and II.

Media test.—Since a neutral or slightly alkaline soil is desirable for the commercial culture of sweet peas, a test was made to determine the most suitable medium for growing peas in gravel culture. The acidity of the 2 WP solutions for each medium was adjusted twice weekly with sodium hydroxide to a pH of 7.0 to 7.5. Table 23 indicates that C grade Haydite is superior to other media used. The cinders used in these tests were alkaline, and the sweet peas produced heavily in this medium. Silica gravel, by nature of its composition, is very acid, and production was low in this medium. Calcareous gravel, although desirable because of its pH range, is not as well aerated as cinders or Haydite and is less desirable for that reason. The B grade Haydite is recommended for commercial use.

TABLE 23.—Production of sweet peas in a 2 WP solution with various media

Medium	Stems per foot of row
C Haydite	197
Silica gravel	83
Coarse cinders	190
Calcareous gravel	114

ASTERS

Commercial culture.—Little difficulty should be experienced growing asters in gravel culture. Transplanting from the seed flat to the bench is recommended over benching with a soil ball although this latter method can be used. Benches can be sterilized by allowing them to dry out thoroughly or by treating with chemicals that will not leave toxic residues.

Comparison of soil and gravel.—A spring crop of asters was grown to determine the usefulness of gravel culture. As shown in table 24, the plants in the media subjected to the various treatments produced more flowers than the plants in soil plots. With the exception of the unlighted plot in Haydite, longer stems with larger flowers also resulted when plants were grown in the WP solution in a modified V-bottom bench.

TABLE 24.—Production of Giant Shell Pink asters in various media

Medium	Type	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	Soil ball intact	6.60	17.36	2.75
C Haydite*	Soil ball intact	6.60	8.00	2.20
C Haydite	Soil ball removed	6.75	17.93	2.90
C Haydite	Soil ball intact	7.78	19.44	3.10
Coarse cinders	Soil ball removed	7.05	18.15	3.11
Coarse cinders	Soil ball intact	7.02	19.94	3.15
Calcareous gravel	Soil ball removed	8.42	18.36	3.13
Calcareous gravel	Soil ball intact	7.45	19.67	3.19
Silica gravel	Soil ball removed	8.42	19.00	2.89
Silica gravel	Soil ball intact	7.86	18.40	2.89

*Unlighted after benching.

Removal of the soil ball.—The increases in production generally noted on plants set in the bench with a soil ball compared with those set after the ball had been removed by washing were not observed with asters. Table 24 shows little difference either in the method of handling or the type of medium used.

BOSTON YELLOW DAISY

Commercial culture.—Plants may be benched directly from the propagation bench or from 2½-inch pots. These plants grow exceptionally well in gravel with either a WP or 2 WP solution.

Comparison of soil and gravel.—Differences in production between Boston yellow daisies grown with the WP solution in a V-bottom bench containing various media and those grown in commercial soil culture were marked. The B grade Haydite is recommended for commercial use.

TABLE 25.—Production of Boston yellow daisies in various media

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil.....	52.1	9.6	2.1
Coarse cinders.....	61.8	13.9	2.3
Calcareous gravel.....	54.8	13.8	2.3
C Haydite.....	74.6	13.4	2.3

More flowers were produced on plants grown in nutrient solutions, though the differences in calcareous gravel were less, possibly because of the alkalinity of this medium. C grade Haydite proved the best medium of those tested. Stem lengths were significantly greater in all media, compared with soil, and flower diameters were one-fourth of an inch larger in all media. The differences in the size of the plants are illustrated in figure 22.



Fig. 22.—Comparative growth of Boston yellow daisy in soil (left) and gravel (right)

PANSY

Commercial culture.—This crop can be grown in the usual manner by benching plants that are well established in 2½-inch pots. Infrequent pumping after benching aids in preventing rot, which often develops on this soft-stemmed crop.

Comparison of soil and gravel.—The production of Oregon Giant pansies in a flat-bottomed bench with a WP solution compared with normal soil culture is shown in table 26.

TABLE 26.—Production of Oregon Giant pansies in soil, cinders, and silica gravel

Medium	Flowers per plant	Stem length, inches	Flower diameter, inches
Soil	7 2	4 0	2 0
Cinders	8 9	5 5	2 4
Silica gravel.....	9 8	4 5	2 0

Although drainage conditions were poor, more flowers with longer stems were produced in gravel than in soil.

Removal of the soil ball.—With Don's Giant pansy, a test was made to determine the most practical commercial method of handling crops in nutrient solution culture. Since it had already been demonstrated many times that removing the ball of soil was detrimental, this phase was omitted. Seed was sown in sand; the seedlings were transplanted to small flats; and when of sufficient size, the seedlings were planted in the bench. Compared with this method, seed was sown in soil, and the seedlings were planted in 2½-inch pots. The resulting plants were set in the bench with the ball of soil as described previously. The results of this experiment are shown in table 27.

TABLE 27.—Production of Don's Giant pansy in C Haydite with a WP solution

Method of handling	Flowers per plant	Stem length, inches	Flower diameter, inches
Silica gravel.....	73.0	7.6	2.19
Ball of soil	111.1	7.5	2.14

The differences in stem length and flower diameter were insignificant, but a decided increase in favor of the soil ball method was noted in the number of flowers produced.

Under conditions of poor drainage, transplanting with a soil ball is not recommended, especially where large particles (three-fourths of an inch) are used as a medium, because the roots develop near the bottom of the bench when the upper portion of the medium dries. As a result, root and stem rots develop quickly, and the presence of a soggy ball of soil under these conditions is detrimental.

FEVERFEW

Commercial culture.—Rooted cuttings direct from the propagation bench or well-established plants in 2½-inch pots may be used as benching stock. The plants grow satisfactorily on a WP solution, but the solution should be raised to a 2 WP level later to prevent the development of light-colored foliage and small flowers.

Comparison of soil and gravel.—A test similar to that with Boston yellow daisy was made with feverfew. In addition, feverfew was planted in C grade Haydite with a ball of soil to determine the effect of this planting method on production.

TABLE 28.—Production of feverfew in various media

Medium	Ounces of cut flowers per plant
Soil.....	11.8
Coarse cinders.....	12.6
Calcareous gravel.....	11.6
C Haydite.....	13.3
C Haydite, planted with a ball of soil.....	22.7

The differences in production were smaller than had been noted with other crops, and calcareous gravel was slightly inferior to soil. The greatest difference occurred where plants were placed in the bench with a ball of soil; the production of these plants was almost doubled.

ORCHIDS

It has long been an accepted practice among orchid growers to grow epiphytic forms on an organic material known as osmunda fiber, the roots of the cinnamon fern and its allies. To this, only water is applied. In some instances, manure water or liquid fertilizer in various forms has been used with varying degrees of success. Most of these trials have been total failures.

Although volumes have been written on the culture of orchids, very little scientific investigation has been done in relation to nutrition, photosynthesis, or respiration.

The work of Knudson (7) on the nonsymbiotic culture of orchid seedlings on an agar medium to which inorganic salts and sugar were added paved the way for further studies on nutrition.

The purpose of this investigation was to determine, if possible, the response of epiphytic orchids, namely those in the *Cattleya* genus, in various stages of growth, to solution culture practices and to various types of media, both organic and inorganic.

Experiments were begun November 1, 1939, in which plants of all stages from seedlings to mature blooming size were used. The plots contained fine Haydite, silica gravel, and osmunda fiber. The solutions used were ½ WP, ¾ WP, and ½ Hoagland TC (Appendix tables I and II).

Preliminary observations for 2 years on small plants indicate that the additions of nutrient solutions were beneficial.

Most of the plants in osmunda fiber were better than those in Haydite and silica gravel. They exhibited less shrinking in the pseudobulbs and seemed to be firmer in texture. These plants were undisturbed at the beginning of the experiment, however, whereas those in silica gravel and Haydite had all fiber removed from the roots, and the shift caused a check in growth.

The response of mature plants to applications of solutions was not as striking as that of the younger plants. The mature plants received a severe check in replanting in the silica gravel and Haydite. Some varieties were definitely weak when planted. The outstanding observation was that varietal characteristics and individual plant vigor play an important part in the growth and development of plants regardless of the treatment applied. Some plants in all blocks appeared healthy and vigorous; others were definitely weak, chlorotic, and shrunk. The plants exhibiting weakness were in silica gravel and Haydite. There seemed to be no differential preference for any medium or chemical solution used.

Seedlings from the flask.—Usually seedlings are taken directly from the flask and planted in small "community pots" at the rate of about 25 to 50 per pot. The process is tedious and slow with many opportunities for failure. If seedlings could be planted in a sand medium and given solutions at intervals, the process might be hastened, and better seedlings produced.

In our tests, seedlings in sand receiving a chemical solution were better than those in osmunda fiber. The plants were larger and darker green in color. The seedlings responded equally well in the one-half concentration of both WP and TC solutions.

Pots that received weekly applications of vitamin B₁ solution in addition to the chemical solutions did not appear to be any different from those not treated.

MISCELLANEOUS CROPS

Euphorbia fulgens.—Plants out of 2½-inch pots, planted with a ball of soil, do exceptionally well in gravel culture if perfect drainage is provided. The 2 WP solution is best.

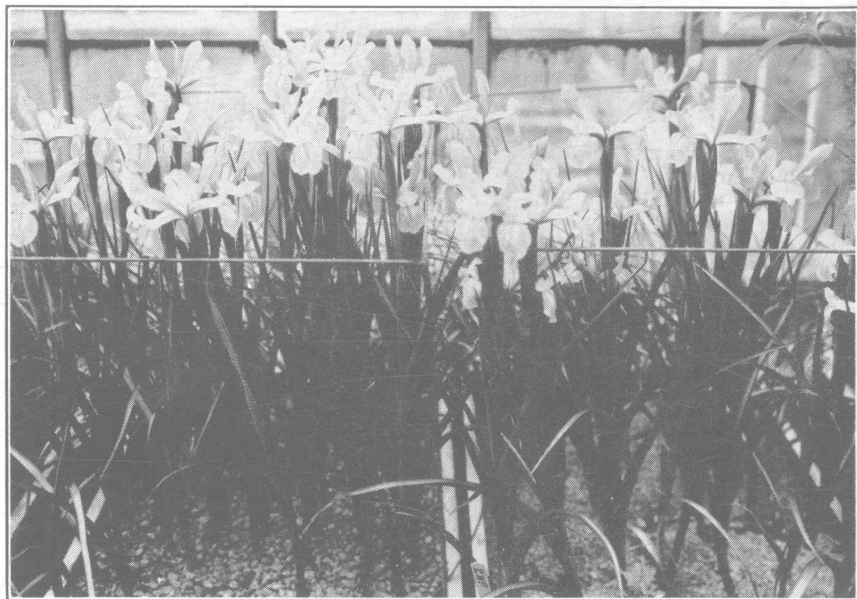


Fig. 23.—Wedgewood iris in C grade Haydite

Calla lilies.—Satisfactory growth and good production result when calla lilies are grown in gravel. It is important that the tubers be free of root rot, since this disease is transmitted readily through the solution from plant to plant. The 2 WP solution is most suitable.

Bulbous and cormous plants.—Gladioli, bulbous iris, narcissi, hyacinths, freesia, ornithogalum, tulips, and many species of the genus *Lilium* were grown satisfactorily in the WP solution.

Tuberous-rooted begonias.—Grown in gravel in a 2 WP solution, these plants produce large flowers in profusion on long stems.

Geraniums.—When grown for stock plants in gravel, geraniums produce large quantities of cuttings of exceptional quality.

Other plants that have been grown successfully in gravel culture since 1937 include calendula, bouvardia, buddleia, gerbera, marigold, candytuft, dahlia, annual chrysanthemums, salpiglossis, centaurea, and didiscus.

COMPARATIVE COSTS OF SOIL AND GRAVEL CULTURE

One of the drawbacks in engaging in the commercial practice of gravel culture is the apparent high cost of installation. The cost is not high, however, if the initial installation costs are prorated over a period of years. An examination of a concrete case will illustrate the point.



Fig. 24.—King Alfred narcissus in C grade Haydite

The difference in cost between the two benches is approximately \$150. If the soil is removed yearly, the additional cost of removal and replacement would amount to about \$20 per year, and with such management, the gravel and soil benches would equalize in cost in 8 years. If, however, the soil is steam-sterilized, it would take about 16 years to secure approximately equal costs. The upkeep of the gravel culture equipment during that period would be equalized by the savings resulting from the reduced cost of fertilizers and manures. On a 100-foot bench, such a saving should amount to about \$5.00 per year. Thus, over a 16-year period, the costs of both benches would be practically equal except for the saving in labor, which would be in favor of the gravel culture method. With roses, the cost of labor per plant grown in soil is 30 cents; for each plant grown in gravel, only 15 cents. This saving, even were the production figures similar, would enable the grower to make a good profit.

Cost of erection and filling of a 100-foot concrete flat-bottomed bench 4 feet wide		Cost of erection and filling of a V-type concrete bench 100 feet long and 4 feet wide	
100 feet of bench	\$100	100 feet of bench.....	\$125
Soil and manure to fill bench .	30	100 feet of half-tile.....	3
Labor	3	Pump.....	35
		Pipe	3
Total	\$133	Time clock	20
		Emulsion.....	2
		Medium.....	30
		Labor	10
		Tank	60
		Total	\$288

For growers having flat-bottomed benches 100 feet long and 4 feet wide, the cost of conversion to a modified V-bottom bench with 1-inch additions of concrete at the sides and a ½-inch addition in the center would be:

Seven bags of cement.	\$ 5.25
AAA Haydite or sand.	2.00
Asphalt emulsion	2.00
Labor	6.00
Half-tile.....	3.00
Pipe.....	3.00
	21.25
Additional equipment of pump, clock, and medium	70.00
Tank.....	60.00
	\$151.25

SUMMARY

Benches constructed for gravel culture should be perfectly waterproofed and built to make possible complete drainage of the solutions.

Tanks should be waterproofed and should be large enough to contain at least 40 per cent of the volume of the benches they serve.

Black pipe should be used in preference to galvanized to avoid toxicity from zinc.

Four-inch half-tile makes the most satisfactory trough for the bottom of the bench.

Sump pumps are easier to install than centrifugal and should be of sufficient capacity to provide rapid flow and quick return.

Haydite, trap rock, silica gravel, cinders, and calcareous gravel make suitable media for plants, although some difficulties may be experienced with cinders and calcareous gravel.

Of all solutions tried, the WP formula was found to be the most satisfactory for the majority of crops.

Solutions should be changed about once in 2 months, although with care, longer intervals may be acceptable.

Colorimetric microchemical tests should be made once a week for pH and phosphorus and once in 2 weeks for nitrates and potassium.

The maintenance of a pH of 6 to 6.5 will be found satisfactory for most crops.

The number of times a day to pump varies with the crop and the season. Four times a day is ample in the summer, and once a day in the winter. Some crops, like carnations, may need even less frequent applications of solutions.

To avoid the formation of algae on the surface of the medium, the solutions should be pumped to within 1 inch of the surface.

To avoid injury to the roots from spray materials, the benches may be flooded with clear water during spraying. After spraying, this water should be discarded and not allowed to drain back into the tanks.

Dormant-budded roses are best for gravel culture and should preferably be planted in January or February. The 2 WP solution has proved very satisfactory for roses, although additions of potassium to it during winter resulted in greater production. The use of ammonium nitrogen at a pH of 5 or below causes yellowing, defoliation, and check of axillary bud development on roses. Grafted or own-root roses can be planted with a ball of soil. Gravel-grown roses can be dried off somewhat similarly to those grown in soil. Frequent syringing of roses is safer in gravel than in soil, since there is no danger of creating too moist a medium. The base of galvanized stakes should be covered with asphalt before use, to avoid toxicity from zinc. Because of optimum conditions in gravel culture, greater production and better quality of roses result.

Stocks, snapdragons, feverfew, and pansies were satisfactory if the ball of soil was retained when they were planted, but the practice of planting small seedlings from the seed flat to the bench is recommended.

Stocks, snapdragons, pansies, feverfew, asters, Boston yellow daisies, sweet peas, and chrysanthemums in gravel culture produced higher quality and more flowers per plant than soil-grown plants.

Chrysanthemums should be benched either as cuttings directly from a propagating bench or else as potted plants. Perfect drainage is essential.

Carnations require less frequent applications of solutions per day than many other crops.

Lilies and gardenias respond well to gravel culture.

The initial costs of equipment are higher for gravel culture than for soil. If its cost is prorated over a period of years, gravel culture is not any more expensive than soil culture, and because of labor savings and greater perfection of growth, it is actually more profitable.

APPENDIX

TABLE I.—Composition of the various nutrient solutions

Nutrient solution formulas	Grams per 1,000 gallons of water	Per 1,000 gal- lons of water		Millimolar concentra- tion
Ohio WP				
Potassium nitrate, 13-0-44, KNO ₃	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, (NH ₄) ₂ SO ₄	439	0	15.5	.9
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	2,043	4	8	2.2
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	1,090	2	6.5	1.4
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	4,856	10	12	7.5
Ohio W				
Potassium nitrate, 13-0-44, KNO ₃	2,630	5	13	6.9
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	2,043	4	8	2.2
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	1,090	2	6.5	1.1
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	4,856	10	12	7.5
Ohio 4				
Potassium nitrate, 13-0-44, KNO ₃	3,940	8	11	10.3
Potassium chloride, 0-0-50, KCl.....	1,113	2	7	3.9
Ammonium nitrate, 35-0-0, NH ₄ NO ₃	1,940	4	4.5	6.4
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	2,180	4	13	2.3
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	9,712	21	7	14.9
Ohio 6				
Potassium nitrate, 13-0-44, KNO ₃	2,630	5	13	6.9
Ammonium sulfate, 20-0-0, (NH ₄) ₂ SO ₄	439	0	15.5	.9
Potassium chloride, 0-0-50, KCl.....	2,225	4	15	7.9
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	2,180	4	13	2.3
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	9,712	21	7	14.9
Ohio 8				
Potassium nitrate, 13-0-44, KNO ₃	5,600	12	6	14.7
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	2,100	4	10	2.3
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	1,400	3	1.5	1.5
Ohio 10				
Potassium nitrate, 13-0-44, KNO ₃	5,260	11	10	13.8
Ammonium sulfate, 20-0-0, (NH ₄) ₂ SO ₄	878	1	15	1.8
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	4,086	9	0	4.4
Sodium hexametaphosphate, 0-69-0, (NaPO ₃) ₆	4,020	8	14	10.4
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	9,712	21	7	14.9
Calcium hydroxide, Ca(OH) ₂	310	0	11	1.1
Ohio 11				
Potassium nitrate, 13-0-44, KNO ₃	1,320	2	15	3.5
Ammonium sulfate, 20-0-0, (NH ₄) ₂ SO ₄	220	0	8	.4
Potassium chloride, 0-0-50, KCl.....	3,340	7	6	11.9
Magnesium sulfate, MgSO ₄ ·7H ₂ O.....	4,086	9	0	4.4
Monocalcium phosphate, 0-48-0, CaH ₄ (PO ₄) ₂ ·H ₂ O.....	2,180	4	13	2.3
Calcium sulfate, CaSO ₄ ·2H ₂ O.....	9,712	21	7	14.9

TABLE I.—Composition of the various nutrient solutions—continued

Nutrient solution formulas	Grams per 1,000 gallons of water	Per 1,000 gal- lons of water lb. oz.	Millimolar concentra- tion
Ohio 12			
Potassium nitrate, 13-0-44, KNO_3	2,630	5 13	6.9
Ammonium sulfate, 20-0-0, $(\text{NH}_4)_2\text{SO}_4$	439	0 15.5	.9
Potassium chloride, 0-0-50, KCl	6,675	14 12	23.7
Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	4,086	9 0	4.4
Monocalcium phosphate, 0-48-0, $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	2,180	4 13	2.3
Calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	9,712	21 7	14.9
Ohio 13			
Potassium nitrate, 13-0-44, KNO_3	5,260	11 10	13.8
Ammonium sulfate, 20-0-0, $(\text{NH}_4)_2\text{SO}_4$	878	1 15	1.8
Potassium chloride, 0-0-50, KCl	4,450	9 13	15.8
Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	4,086	9 0	4.4
Monocalcium phosphate, 0-48-0, $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	2,180	4 13	2.3
Calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	9,712	21 7	14.9
Ohio 15			
Potassium nitrate, 13-0-44, KNO_3	5,260	11 10	13.8
Ammonium sulfate, 20-0-0, $(\text{NH}_4)_2\text{SO}_4$	878	1 15	1.8
Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	4,086	9 0	4.4
Sodium hexametaphosphate, 0-69-0, $(\text{NaPO}_3)_6$	1,600	3 9	4.2
Calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	9,712	21 7	14.9
Calcium hydroxide, $\text{Ca}(\text{OH})_2$	310	0 11	1.1
Purdue 2D			
Magnesium sulfate, MgSO_4 (anhydrous).....	246	0 9	.5
Treble superphosphate, 0-48-0, $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	586	1 5	.6
Potassium nitrate, 13-0-44, KNO_3	4,158	9 3	10.9
Calcium sulfate (gypsum), $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	2,873	6 5.5	4.4
Ammonium sulfate, 20-0-0, $(\text{NH}_4)_2\text{SO}_4$	529	1 3	1.1
Purdue 2E			
Magnesium sulfate, MgSO_4 (anhydrous).....	246	0 9	.5
Treble superphosphate, 0-48-0, $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	586	1 5	.6
Potassium nitrate, 13-0-44, KNO_3	2,495	5 8	6.5
Calcium nitrate, 15.5-0-0, $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	2,722	6 0	3.0
Ammonium nitrate, 35-0-0, NH_4NO_3	605	1 5.5	2.0
New Jersey (carnation)			
Ammonium sulfate, 20-0-0, $(\text{NH}_4)_2\text{SO}_4$	600	1 5	1.2
Monobasic potassium phosphate, KH_2PO_4	2,280	5 0.5	4.4
Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	2,320	5 2	2.5
Calcium nitrate, 15-0-0, $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	7,000	15 7	7.8
Hoagland's TC			
Monoammonium phosphate, $\text{NH}_4\text{H}_2\text{PO}_4$	434.7	0 15.3	1.0
Potassium nitrate, KNO_3	2,293.2	5 1.0	6.1
Calcium nitrate, $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	3,568.5	7 13.5	4.0
Magnesium sulfate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	1,863.5	4 1.8	2.0

TABLE II.—Parts per million composition of some nutrient solution formulas
Based on complete solubility of all salts

Formula	Ni- trate	Am- moni- um	Am- moni- um to ni- trate	Total nitrogen as ni- trate	Phos- phor- us	Phos- phate	Po- tassi- um	Calci- um	Mag- nesi- um
Ohio WP.....	400	28	100	500	65	200	250	310	51
Ohio W.....	400	.....	.....	400	65	200	250	310	51
Ohio 4.....	983	113	390	1,373	130	400	465	620	102
Ohio 6.....	400	28	100	500	130	400	500	620	102
Ohio 8.....	845	.....	.....	845	84	256	530	54	53
Ohio 10.....	800	56	200	1,000	322	987	500	580	102
Ohio 11.....	200	14	50	250	130	400	495	620	102
Ohio 12.....	400	28	100	500	130	400	990	620	102
Ohio 13.....	800	56	200	1,000	130	400	995	620	102
Ohio 15.....	800	56	200	1,000	128	392	500	580	102
Purdue 2D.....	627	36	124	751	31	96	395	200	120
Purdue 2E.....	835	35	120	955	31	96	237	200	120
New Jersey (carnation).....	875	40	140	1,015	130	408	170	283	58
Hoagland's TC.....	868	18	62	930	31	95	235	160	49

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